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For: **SERVICE VEHICLE FOR PERFORMING IN-SPACE  
OPERATIONS ON A TARGET SPACECRAFT,  
SERVICING SYSTEM AND METHOD FOR USING  
A SERVICE VEHICLE**

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**LETTER RE: PRIORITY**

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Sir:

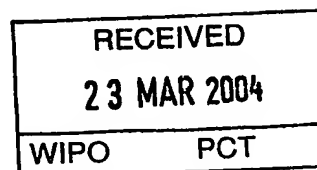
Applicant hereby claims priority of German Application Serial No. 102 59 638.7, filed 18  
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Respectfully submitted,

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**Prioritätsbescheinigung über die Einreichung  
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**Bezeichnung:** Service vehicle for performing in-space operations on a target spacecraft, servicing system and method for using a service vehicle

**IPC:** B 64 G 1/00

Die angehefteten Stücke sind eine richtige und genaue Wiedergabe der ursprünglichen Unterlagen dieser Patentanmeldung.

München, den 4. Februar 2004  
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**Abstract**

A service vehicle (6) for performing in-space operations on a selected target spacecraft (2), shall be provided such that a particularly versatile and flexible service for performing in-space operations on the target spacecraft (2) is possible. Furthermore, a servicing system (1) and a method for in-space servicing of spacecraft (2) shall be provided. With this object, according to the invention the service vehicle (6) comprises a communication module (60) which with respect to its transmission characteristics is configurable in order to meet given receiver parameters of said selected target spacecraft (2). Furthermore, according to the present invention the selected target spacecraft (2) is used to relay transmitted signals or information from the service vehicle (6) to a ground control module (12).



Fig. 1

## Description

The invention relates to a service vehicle for performing in-space operations on a target spacecraft. It furthermore relates to a servicing system and to a method for in-space servicing of spacecraft.

Spacecraft in general need to be properly positioned in a predetermined orbit and be properly oriented in the three-dimensional space with respect to their service areas in order to fulfill their respective mission. In other words, they typically are designed to have their telecommunication equipment looking to (or pointing to) the service area. Various forces such as moon gravity, sun gravity, non-uniformity of gravity potential of earth, solar pressure, and atmosphere in low altitudes, and even Venus gravity, plus many other less important forces, interact with the spacecrafts and tend to change their optimum position and orientation. These sources alter the orbital elements of the respective spacecraft effecting what is called orbit perturbations. To counteract these perturbations, spacecraft are provided with thrusters, which are used either in continuous mode or in pulse mode or occasionally, from time to time (i.e. every a few days/weeks/months). Said thrusters consume fuel in order to effect the counteracting forces.

Artificial satellites are a particular case of spacecraft as their mission involves orbiting a specific celestial body in order to be able to provide their service. Other spacecraft have trajectories that may differ for part of their mission from the classical definition of satellite orbiting but still have a service area where they have to point to and accordingly may be negatively influenced by similar perturbations. Usually they become satellites of another celestial body or simply float in space at a Lagrange point or elsewhere. The same nature of problems pertains to all type of spacecraft as regards their orbit and health issues. For reasons of clarity, the following description focuses on a satellite in the proximity of earth and in particular in a proximity that teleoperation capability is not hindered by long electromagnetic wave propagation times, although the concepts may also be relevant to other kinds of spacecraft.

A spacecraft that can be kept, by means of its thrusters, in a desired target position and attitude is considered under control or controllable, and a non-controllable spacecraft is out of control with regard to its position and attitude. Said controllable spacecraft can be

1 more easily and safely approached for servicing, and is called "co-operative", while a  
2 spacecraft that has lost its attitude control is called "non co-operative".

3  
4 Typical spacecraft are designed for a so-called "designed lifetime". The "designed lifetime"  
5 of a spacecraft has a statistical definition. Spacecraft are designed to have an operational  
6 lifetime of e.g. 10 years at minimum, with an associated probability 98% (based on  
7 the statistical lifetime of the selected components). This means that in the term of 10 years  
8 a portion of 2% of the spacecrafts of the same design and material and processes  
9 would fail and the rest would continue to function. The average lifetime of the materials of  
10 a spacecraft is much longer, sometimes 3 times the "designed lifetime". For example, the  
11 voyager spacecraft still operate after 25 years, while most of the telecommunication satellites  
12 have a designed lifetime of 6 to 15 years.

13  
14 The spacecraft are designed to carry a predetermined amount of fuel, which is calculated  
15 in dependence of what they would need to consume during their "designed lifetime". Consequently,  
16 a spacecraft carries fuel only for the designed lifetime (e.g. 10 years) in order  
17 to perform all types of maneuvers. At a certain point of time, when fuel reserves finish, a  
18 spacecraft cannot retain even its attitude correct and so it becomes useless.

19  
20 When the fuel reserves are very limited, then the spacecraft can no longer provide the  
21 same level of service that it was designed for, or even provide any useful service at all. In  
22 this case the spacecraft is rendered useless and abandoned in space creating an additional  
23 problem of potential collision with a future operational spacecraft. It becomes as it is  
24 called „space debris“.

25  
26 Fuel-depletion that renders the spacecraft uncontrollable and therefore useless, may  
27 happen even earlier than the designed lifetime of the spacecraft for various reasons (e.g.  
28 simple bad calculation of the fuel budget, wrong positioning due to error, malfunctioning  
29 of the launcher, rare phenomena, accident or otherwise, during the launch phase; wrong  
30 positioning of the spacecraft during the LEOP (Launch and Early Orbit Phase) due to error,  
31 malfunction, rare phenomena, accident or otherwise; change in mission; errors, malfunctions,  
32 rare phenomena, accidents, or otherwise during the remaining actual lifetime).

33  
34 In general, any component, unit, subsystem of a spacecraft, such as sensors, actuators,  
35 processing units, inertial subsystems, power subsystem, software, communication pay-

1 load, may fail due to errors in its use, malfunction, rare phenomena or otherwise that may  
2 render the spacecraft partially or totally, temporarily or permanently uncontrollable and  
3 therefore unable to function properly to generate the opportunity revenue, or any revenue.  
4 It may even create a significant risk for other spacecrafts by its status as space debris. In  
5 this definition of space debris we will add to the traditionally conceived one, that regards  
6 space debris as passive objects, the characteristic of potentially active object that may be  
7 even more dangerous than a passive debris, as an active and unpredictable (accelera-  
8 ting, decelerating) moving object may be.

9  
10 For both reasons, i. e. lifetime restrictions due to limited fuel resources as well as system  
11 failure due to unexpected error, servicing capabilities for spacecraft with the general goal  
12 of artificially extending the lifetime of a spacecraft are highly desirable, particularly in  
13 view of the typically very high costs involved with replacing an existing spacecraft by a  
14 substitute.

15  
16 Several inventions have been developed for solving the problem of providing servicing  
17 capabilities for spacecraft, particularly with respect to failure on satellites and fuel-  
18 depletion (US 5,410,731, US 5,813,634, WO 0103310), disclose concepts to inspect the  
19 satellites on orbit (US 6,296,205, US 6,384,860), disclose concepts to provide service to  
20 them on orbit (WO 9731822, US 4,896,848, US 4,273,305, US 5,299,764, US 4,349,837),  
21 or prepare for servicing (US 4,946,596, EP 1 101 699, US 4,657,221). Several others  
22 have developed concepts for tools to perform the service (US 4,177,964, WO 0208059)  
23 or developed methods for providing new services (EP 1 245 967) for which this invention  
24 provides improvements.

25  
26 Various systems have been studied, wherein the method for performing the rendezvous  
27 typically is carried out by manual Tele-operation. In some other documents, autonomous  
28 rendezvous and docking systems are proposed.

29  
30 In the case of autonomous docking mechanisms, the designs that have been proposed  
31 involve a robotic arm which demands high dry mass and power budgets.

32  
33 Patent US 5,299,764 discloses a system for carrying out in-space servicing of spacecraft,  
34 wherein artificial life robotics are utilized.

1 Patent US 6,296,205 discloses a concept of inspecting the RF functioning of a satellite at  
2 proximity and emitting control signals and diagnostics to the ground.

3  
4 Patent US 6,384,860 discloses a video telemetry system for monitoring the deployment of  
5 an apparatus coupled to a satellite. This allows the solar panels to be observed during  
6 deployment and even before said panels are deployed, but at very low rate (one frame  
7 every 27 seconds), said rate not permitting any real teleoperation and any other service.

8  
9 In the cases where teleoperated designs of service vehicles are proposed these are dis-  
10 advantaged by the high bandwidth required from the service vehicles to support the  
11 teleoperation. To perform an inspection or rendezvous and docking to a satellite a high  
12 bandwidth link needs to be established for certain minutes or hours in order to provide  
13 sufficient and timely (real time) visual information to the operators and systems on earth  
14 to perform the servicing ( inspection, rendezvous, docking ). Such designs have been  
15 proposed resulting in the GSV Geostationary Service Vehicle concept spacecraft.

16  
17 The disadvantages of this category of prior art are:

- 18 ■ High electric power budgets, in order to cope with the required high bandwidth trans-  
19 mission for transmitting timely (in real time) the output of the rendezvous sensors (ra-  
20 dar, visual images) towards the ground stations.
- 21 ■ High mass budget for the Mission Communication payload, batteries; solar cells, plus  
22 structural overhead and overheads to the attitude control subsystem (flywheels,  
23 thrusters...) .
- 24 ■ High volume as result of the above increased budgets (mass, structural overhead,  
25 protruding antennas, protruding solar panels).
- 26 ■ High complexity due to the redundancy required.
- 27 ■ Higher vulnerability to radiation hazards and debris (larger profile).
- 28 ■ Low range of operation as regards delta velocity potential.
- 29 ■ Large consumption of consumables (fuels, pressurization gas).
- 30 ■ Low maneuverability due to high volume and mass.
- 31 ■ Higher risks of client due to higher mass and volume and lower maneuverability.
- 32 ■ Larger debris problem at end of its life.

33  
34 The complexity of service missions to orbiting satellites and the high cost involved (space  
35 shuttle cost is 500 M\$ per flight) has rendered the idea of servicing ailing satellites as a

1 solution to restore or prolong service unattractive. As an alternative, putting into orbit uni-  
2 versal back-up satellites or specifically designed, individual backup satellites is consid-  
3 ered.

4  
5 The Geostationary satellites in order to reach their orbit need to use some kind of launch  
6 vehicle of which vehicle either the last part (upper stage) or the apogee kick motor is jetti-  
7 soned in the space close to the geostationary ring creating space debris. Said debris con-  
8 stitutes a high hazard potential for future missions. Some recent satellites use a Unified  
9 Propulsion System for reaching geosynchronous orbit from their injection point and for  
10 orbit maintenance. This solution saves one piece of debris but results to higher mass  
11 overheads for the duration of the entire life of the satellite. At the end of life of the satellite  
12 the totality of it becomes space debris.

13  
14 Up to now, almost no spacecraft has been designed to be refueled or be serviced in  
15 space. As one result of this design philosophy, a large part of space debris consists of  
16 spent spacecrafts and apogee kick motors and upper stages.

17  
18 Therefore, it is an object of the present invention to provide a particularly versatile and  
19 flexible service vehicle for performing in-space operations on a target spacecraft.  
20 Furthermore, a servicing system and a method for in-space servicing of spacecraft shall  
21 be provided.

22  
23 With respect to the service vehicle, this object is achieved with a communication module  
24 which with respect to its transmission characteristics is configurable in order to meet gi-  
25 ven receiver parameters of said selected target spacecraft.

26  
27 The services provided by the service vehicle may include any types of services, such as  
28 refueling, delivering all kinds of material, repair or maintenance services, or other kinds of  
29 suitable activities. Said services may collectively be denoted as ACR for Assembly, Con-  
30 vert and Repair. The majority of said ACR services are to be performed by means of te-  
31 leoperation assisted by stereoscopic means, illuminating means & tape-tools that assist in  
32 fetching/storing tools and fetching/storing spares and fetching/storing disassembled com-  
33 ponents.



1 The invention is based upon the concept that for flexible and versatile servicing of a target  
 2 spacecraft, the service vehicle ought to be designed for a particularly low mass, energy  
 3 and/or fuel budget. However, a significant contribution to both mass and energy/fuel re-  
 4 quirements is the necessity to constantly provide for reliable communication between the  
 5 service vehicle and a ground control station, in particular in view of the comparatively lar-  
 6 ge distances that must be overcome between ground control and service vehicles in ex-  
 7 pected servicing missions. In order to significantly lower the onboard power consumption  
 8 on the service vehicle necessary for maintaining a reliable communication channel with  
 9 ground control, the service vehicle is designed for emitting signals to ground control by  
 10 using the target spacecraft to be serviced as a relay station. In this concept, the energy  
 11 required from the service vehicle may be limited to maintain a communication channel  
 12 with the target spacecraft, and accordingly the mass required to provide these lowered  
 13 energy levels – i. e. accumulator mass – may be kept correspondingly low. The major  
 14 share of the energy necessary to maintain proper communication in this concept is then  
 15 delivered by the target spacecraft which as such is designed for communicating with  
 16 ground control anyway. In order to render the target spacecraft useable for this purpose,  
 17 the service vehicle is designed to be configurable to establish communication contact with  
 18 the target spacecraft.

19  
 20 Particularly advantageous features of the present invention are specified in the dependent  
 21 claims.

22  
 23 In a preferred embodiment, the service vehicle is designed with particular emphasis on  
 24 the concept to keep the target spacecraft safe from over-extensive or potentially destruc-  
 25 tive energy input from the service vehicle while also providing for a comparatively high  
 26 range of distances to the target spacecraft over which reliable communication may be  
 27 established. In order to achieve these accumulated goals, which with respect to the output  
 28 power emitted by the service vehicle contradict each other, the service vehicle preferably  
 29 is designed for variable output power of its communication module. For this purpose, the  
 30 service vehicle preferably is equipped with a control module for providing a setpoint for  
 31 an output power of said configurable communication module. In further preferred embo-  
 32 diments, the setpoint for the output power is chosen in dependence of the current distan-  
 33 ce between service vehicle and target spacecraft and/or the relative orientation of the  
 34 target spacecraft with respect to the service vehicle. Accordingly, the control module pre-  
 35 ferably inputwise is connected to a first position sensor, said first position sensor deli-

1 vering a set of data characteristic for the current position of said service vehicle, to a se-  
2 cond position sensor, said second position sensor delivering a set of data characteristic  
3 for the current position of said target spacecraft, and/or to an orientation sensor, said ori-  
4 entation sensor delivering a set of data characteristic for the current orientation of said  
5 target spacecraft in relation to said service vehicle.

6  
7 In a particularly advantageous embodiment, which may also be used independently from  
8 the communication concept as identified, the service vehicle is designed for reliable and  
9 easy-to-use docking at the target spacecraft. For this purpose, it preferably comprises a  
10 docking system, said docking system comprising a hollow first axle inside of which a se-  
11 cond axle is moveably disposed, said second axle carrying an activateable arrow tip. For  
12 docking purposes, the activateable arrow tip may be inserted into the exhaust system of  
13 the thrusters of the target spacecraft via the axle system. Once inserted into the interior of  
14 the exhaust system, the arrow tip, preferably a double-arrow tip, may be activated in order  
15 spread the arrow fingers apart. Retracting the arrow tip via the axle system will then cau-  
16 se the arrow tip to engage with the side walls of the engine exhaust, thus providing for  
17 reliable docking at the target spacecraft.

18  
19 With respect to the servicing system, the object identified above is achieved with a ser-  
20 vice vehicle as described above, further supplemented by a ground control unit for deli-  
21 vering operational commands to the service vehicle. In order to consequently use the tar-  
22 get spacecraft for relaying communication signals from the service vehicle to ground con-  
23 trol in this servicing system, the ground control unit preferably is set up to receive data  
24 from the service vehicle by using the target spacecraft as a relay station for signals emit-  
25 ted from the service vehicle.

26  
27 The servicing system may further be supplemented by an orbit-based service base for the  
28 service vehicle and/or by a propulsion module attachable to said service vehicle.

29  
30 With respect to the method for in-space servicing of a selected target spacecraft, the ob-  
31 ject identified above is achieved in that a service vehicle as identified is used to perform  
32 selected in-space operations on the target spacecraft, whereby operational signals from  
33 the service vehicle are transmitted to a ground control unit by using the target spacecraft  
34 as a relay station for the operational signals.

1 Among others, the main advantages of the present invention are that particularly inex-  
2 pensive apparatus and methods for performing particularly inexpensive science missions  
3 from space, requiring consumables or/and robotic facilities, are provided. Furthermore,  
4 particularly inexpensive apparatus and methods for altering orbits of passive or active  
5 objects in space for whatever reason (anti-collision, operational) or maintaining its position  
6 against perturbing forces are provided as well as inexpensive apparatus and methods for  
7 effecting reconfiguration, maintenance and/or assembly operations. Still furthermore, the  
8 invention pertains to reusable synergetic apparatus and methods for performing inexpen-  
9 sively a variety of proximity operations, e.g., inspection of an operational or -non-  
10 operational satellite, to determine its status, (its weight, its temperature profile, the opera-  
11 tion or its subsystems), and/or to reusable synergetic apparatus and methods for inex-  
12 pensively delivering or replenishing supplies to orbiting spacecraft or complexes such as  
the international space station.

15 Furthermore, to ground or elsewhere a high bandwidth telecommunication link originating  
16 from a simple inexpensive low powered servicing module is provided, optionally together  
17 with a simple method of controlling a spacecraft through part of the telemetry produced by  
18 another spacecraft, and/or an inexpensive apparatus and method for recovering telemetry  
19 information from a spacecraft whose telemetry means transmit at very low power. Still  
20 furthermore, the invention provides apparatus and method for recovering telemetry infor-  
21 mation from a spacecraft whose telemetry means transmit in very low power and encrypt  
22 it before retransmission through on-board means or through means of the serviced  
23 spacecraft, and/or an inexpensive simplified mechanical grip for capturing a satellite from  
24 the interior of the combustion chamber of the satellite and method of securing the grip,  
resulting to a pair of bodies (satellite & service module) of high stability.

27 An in-space service vehicle, in order to provide even the minimum of services, namely  
28 inspection, it requires to be equipped with one or more cameras and means to establish  
29 an associated High Bandwidth Communication Link (HBCL) to the ground. Through this  
30 link it provides in real-time, the visual or infrared or other high bandwidth information that  
31 is captured, to teleoperators at the ground, to enable teleoperation. The said link requires  
32 very demanding resources (power, telecommunication means), especially if the service is  
33 to be offered at the geostationary ring level.

1 The method in accordance with the invention includes usage of telecommunication means  
2 of said satellit for the transmission of the said images to teleoperating controllers at the  
3 ground segment and not effecting as usually has been proposed, the link directly to the  
4 Ground Stations in an autonomous manner. The service vehicle proposed possesses  
5 means for transmitting at low power and at the frequency of an operational up-link trans-  
6 ponder of the target spacecraft 2 the video signal properly modulated. The satellite shall  
7 retransmit as normally the respective converted and amplified signal through the respecti-  
8 ve down-link transponder. Preferably, the up-link transponder of the operational trans-  
9 ponder chosen for the said link shall cease operation during the service mission to allow  
10 unhindered image reception to the Ground Segment.

11  
12 An exemplary embodiment of the present invention is explained in greater detail with refe-  
13 rence to the drawings in which:

14  
15 Fig. 1 shows a first version of a servicing system for providing in-space service operations  
16 to a selected target spacecraft,

17  
18 Fig. 2 shows a second version of a servicing system for providing in-space service opera-  
19 tions to a selected target spacecraft,

20  
21 Fig. 3 shows a service vehicle of the servicing system according to Fig. 1 or Fig. 2 docked  
22 to the target spacecraft,

23  
24 Fig. 4 shows a schematic structure of the communication system of the service vehicle  
25 according to Fig. 3,

26 Fig. 5 shows a utility base of the servicing system according to Fig. 1 or Fig. 2,

27  
28 Figs. 6a, b show a flexible storage module of the utility base according to Fig. 5 in inflated  
29 (Fig. 6a) and deflated (Fig. 6b) condition, respectively,

30  
31 Fig. 7 shows a schematic view of the internal layout of an equipment and storage bay of  
32 the utility base according to Fig. 5,

Figs. 8a-c show a robotic manipulator for use in the interior of the equipment and storage bay according to Fig. 7 in side view (Fig. 8a) and in top view (Fig. 8b) and a cross section of a rail system for the robotic manipulator (Fig. 8c),

Fig. 9 shows a docking and refueling rack of the utility base according to Fig. 5,

Figs. 10 a, b show a side panel (Fig. 10a) and a top panel (Fig. 10b) of the docking and refueling rack according to Fig. 9,

Fig. 11 shows a catch system, particularly for use in the utility base according to Fig. 5, and

Fig. 12 shows an action tip for the catch system according to Fig. 11.

In all figures, identical parts are provided with identical reference numerals.

Following terms as used herein mean:

**Spacecraft:** is any type of manmade apparatus that is launched in space as a whole or produced through assembly in space.

**Satellite:** is a spacecraft that has entered a roughly determined orbit around a celestial body (planet, natural satellite or sun). "Orbital elements" are called the set of parameters that are describing this orbit.

**Delta velocity:** is the velocity increment or decrease of a spacecraft with respect to its vector of motion, by the application of a force that is called thrust and is provided through the thrusters of the spacecraft.

**Total delta velocity potential:** is the cumulative sum of the delta velocity a spacecraft can generate throughout its operational life.

**Geostationary object:** is an object that has an eastwards circular orbit around earth at a height of about 35,786.4 KM above the sea level. Characteristic of tremendous significance of this orbit is the fact that the object rotates with the same angular velocity as the

1 earth and so it is visible as stable above the equator at certain Longitude, making possi-  
2 ble the continuous communication with it through a single stably pointing antenna. The  
3 sub-satellite point is stable and is located at a certain longitude at the equator.

4  
5 Station keeping maneuvers: are these maneuvers that are required to put or return a  
6 spacecraft to its desired point (or trajectory for missions with no stable sub-satellite point  
7 eg Molniya) of operation.

8  
9 Fail-Safe: a technical characteristic of an apparatus that is designed in such a way that  
10 when it fails for any reason it does not pose a risk apart from the loss of service it is de-  
11 signed to offer.

12  
13 The servicing system 1 according to Figs. 1 and 2 is designed to provide in-space service  
14 operations to a selected target spacecraft 2, in particular a target satellite, at both high  
15 reliability levels and low fuel/cost levels. In this context, the servicing system is designed to  
16 provide the services both to so-called cooperative (or controllable) targets as is shown in  
17 Fig. 1, or to non cooperative (or non controllable) targets as is shown in Fig. 2.

18  
19 In order to provide services in a broad variety of missions, typically in each mission type  
20 units of several, in particular three, species are used. These various species of space-  
21 craft, in various numbers depending upon mission, co-operate in a synergetic manner in  
22 order to provide a service to the target spacecraft 2, either cooperative or non-  
23 cooperative.

24  
25 As a first element, the servicing system 1 comprises a module serving as a utility base 4,  
26 in the role of mothership for further elements. The second element, a service vehicle 6,  
27 has the role of the actual service provider to the target spacecraft 2 and may also be re-  
28 ferred to as a "Utility Agent service vehicle 6". A third element is an engine module 8, po-  
29 tentially a subset of the service vehicle 6, suitable for permanent orbit maintenance ser-  
30 vice on a cooperative target. As fourth element, a specialized vehicle 10 for missions with  
31 non-co-operative targets, or for carrying and operating specialized repairing means or  
32 communication relay means, also referred to as "Escort Agent EA" may be provided.

33  
34 By use of the servicing system 1, the existing fleet of spacecraft can be adequately ser-  
35 viced and upgraded, and future spacecraft can be produced at much lower cost, much

1 lower mass and much shorter time, making use of the advanced repairing and upgrading  
2 capabilities of the service fleet of the servicing system 1. Operational life of spacecraft is  
3 extended, capabilities are augmented, space debris problem is mitigated. In this context,  
4 the service vehicle 2 is designed to provide a series of operations dissimilar in nature and  
5 complexity. In general, a single service vehicle that would embody all potential characteri-  
6 stics would be too expensive to construct, as many studies have shown. Furthermore, its  
7 size and weight would increase the risk and operational cost. Taking into account the po-  
8 tentially large variety of mission types and that it would require to perform high and often  
9 changes in velocity any saving in weight budget would pay back many times.

10  
11 Therefore, the service vehicle 6 is designed for particular weight-effectiveness and flexibi-  
12 lity. This primary goal is achieved by the fundamental design philosophy that it is specially  
13 designed to be teleoperated through a high bandwidth link via the target spacecraft 2 it-  
14 self. On that respect it remains autonomous from the utility base 4 for long although small  
15 and it gains reusability potential by the means of the utility base 4. Accordingly, in order to  
16 allow for low energy consumption and the corresponding savings in weight (i. e. for ener-  
17 gy storage devices such as batteries), the service vehicle 6 is designed to communicate  
18 with a ground control module 12 via a relay station. In the operating mode as shown in  
19 Fig. 1, the target spacecraft 2 itself is used for relay purposes. As indicated by the arrows  
20 14, 16, signals emitted by the service vehicle 6 are transmitted to the target spacecraft 2,  
21 thus according to close proximity demanding only limited transmission power. The service  
22 vehicle 6 emits the signals to the target spacecraft 2 in such a way that the target space-  
23 craft 2 is operated to forward the signals to the ground control module 12, for this purpose  
24 providing the required (comparatively high) transmission power from its onboard energy  
25 sources.

26  
27 In case a non-cooperative target spacecraft 2 is to be serviced, as is shown in Fig. 2, the  
28 service vehicle 6 may be accompanied by a specialized vehicle 10 in this context provi-  
29 ding the necessary transmission power.

30  
31 In order to facilitate using the target spacecraft 2 for the intended relaying purposes, the  
32 service vehicle 6 is equipped with a communication module that can be configured such  
33 that it can communicate with an arbitrary target spacecraft 2 in order to command it to  
34 forward incoming signals to ground control module 12.

1 The service vehicle 6 is shown in more detail in a position docked to the target spacecraft  
2 2 in Fig. 3. Within an outer main body 20, a plurality of servicing facilities (not shown in  
3 detail, but selected appropriately to provide the service required) is disposed. Attached to  
4 the main body 20, there is a separable propulsion system 22 mainly based on the use of  
5 conventional thrusters. In order to firmly attach itself to the target spacecraft 2 after the  
6 final approach, the service vehicle is equipped with a docking system 24 designed to en-  
7 gage with the exhaust system 25 of the target spacecraft 2. In order to provide visual in-  
8 formation for final approach, or to inspect the target spacecraft 2, a number of cameras  
9 26 is attached to the main body 20.

10  
11 The service vehicle 6 is equipped with a built-in communication system 28, which datawi-  
12 se is connected to an altitude and orbit control system 30 of the service vehicle 6. The  
communication system 28 is designed to, at close enough distances, establish a commu-  
13 nication channel with the so-called up-link communication channel of the target spacecraft  
14 2. For this purpose, as indicated by the dashed line 32, the communication system 28  
15 establishes a communication channel with a receiver 34 of the up-link channel of the tar-  
16 get spacecraft 2. Via this communication channel, the communication system 28 trans-  
17 mits commands or signals at a comparatively low output level that within the target  
18 spacecraft 2 are relayed and forwarded to the emitter 36 of the so-called down-link chan-  
19 nel of the target spacecraft 2. As indicated by the arrow 38, the signals are then forwar-  
20 ded via the down-link channel to the ground control module 12 at a comparatively high  
21 transmission power, the energy for which is derived from the on-board energy sources of  
22 the target spacecraft 2.

23  
24 For easier maneuvering relative to the target spacecraft 2, the service vehicle 6 is equip-  
25 ped with a laser unit 39 set up to identify the distance of the service vehicle 6 from the  
26 target spacecraft 2.

27  
28 The docking system 24 of the service vehicle 6 mainly comprises a hollow axle 40, an  
29 activation axle 42 inside the hollow axle driven by a fail-safe mechanism 44 that allows  
30 extension, retracting or rotation of the hollow axle. At the free end of the activation axle  
31 42, a double arrow opening tip 46 (one arrow being smaller than the other) is provided.  
32 The double arrow opening tip 46 is opening by means of retracting the activation axle 42  
33 and an even surface around the activation axle 42 to permit even contact of the front  
34 surface 48 of the service vehicle 6 with the nozzle ring 50 of the exhaust channel 52 of  
35 the target spacecraft 2, providing high stability when engaged.



1  
2 The method of docking consists of the following phases: alignment of axle 40 to nozzle  
3 50, entering the activation axle 42 into combustion chamber 54 of the target spacecraft 2,  
4 opening of the arrowheads, rotation if needed with stepwise retracting, final retracting of  
5 hollow axle 40 and fail-safe engaging of the double arrow opening tip 46 with the interior  
6 of the combustion chamber 54.

7  
8 At approaching the target spacecraft 2, the arrow head sides shall be aligned parallel to  
9 the axle 40. The axle 40 is guided towards the center of the combustion chamber 54  
10 through the nozzle 50 and when it passes the neck of the chamber 54 the arrow head  
11 sides are opened wide to the maximum, through retracting the activation axle 42 in order  
12 to secure it inside the combustion chamber 54. If the angular alignment between service  
13 vehicle 6 and target spacecraft 2 is satisfactory then the securing and safeing phase is  
14 started, if not then the mechanism 44 retracts the hollow axle 40 and rotates the activa-  
15 tion axle 42 in successive steps until the desired angular alignment is achieved. Then the  
16 retreating mechanism 44 retreats slowly and firmly the hollow axle 40 until the surface of  
17 the service vehicle 6 reaches and presses onto the nozzle end-ring of the target space-  
18 craft 2. The activation axle 42 is fail-safe secured at this position and is released only by  
19 command or if a general failure occurs. In case of a power failure or mechanical failure or  
20 processing failure the activation axle 42 is left to its natural position by means of a spring  
21 that forces the arrowheads close. An independently powered timer controls the safeing  
22 mechanism. As long as the anomaly detection mechanism has detected no anomaly  
23 threatening the target spacecraft 2, the activation axle 42 pushes open the arrowheads. In  
24 the case a threatening anomaly is detected the activation axle 42 is left free and, forced  
25 by a spring, lets the arrowheads close. Any forward movement of the target spacecraft 2  
26 lets the service vehicle 6 to free float in space.

27  
28 The structure of the communication system 28 of the service vehicle 6 is shown schema-  
29 tically in Fig. 4. As a key component, the communication system comprises a communi-  
30 cation module 60 which is designed such that with respect to its transmission characteri-  
31 stics it may be configured in order to meet given receiver parameters of the selected tar-  
32 get spacecraft 2. Accordingly, by proper configuration of the communication module 60,  
33 communication with any kind of target spacecraft 2 may be established and hence the  
34 service vehicle 6 can be teleoperated by using the target spacecraft 2 for relaying signals.

1 The communication module 60 comprises a multiplexer 62, connected to a signal modu-  
2 lator 64. Multiplexer 62 together with modulator 64 generate the signals to be transmitted.  
3 For transmission purposes, the communication module 60 further comprises a transmitter  
4 66 in connection with the modulator 64. For configurability, the transmitter 66 is equipped  
5 with a controller module 68, which if supplied with the required data format may reconfigu-  
6 re the transmission characteristics of the transmitter 66 on a software basis. Furthermore,  
7 within the communication module 60, the transmitter 66 is exchangeable. Accordingly,  
8 configuration of the communication module 60 may also be carried out in a hardware  
9 manner by providing an alternative transmitter 66. Since there are a plurality of satellite  
10 types or categories, preferable configuration is carried out on a hardware basis, i. e. by  
11 replacing the transmitter 66, if reconfiguration between different target spacecraft catego-  
12 ries is desired, whereas reconfiguration is done on a software basis, i. e. by reprogram-  
13 ming the controller module 68, if reconfiguration between different individual target  
14 spacecraft of the same category is desired.

15  
16 Inputwise, the multiplexer 62 is connected to an encoder 70, which in turn receives its  
17 input data from a camera 72 and/or a proximity sensor 74. Furthermore, the multiplexer  
18 62 inputwise is also connected to a telemetry system as indicated by the arrow 76.

19  
20 With respect to its output power, the transmitter 66 is adjustable in order to make sure  
21 that the power emitted will not endanger or destroy the target spacecraft 2 due to close  
22 proximity. Accordingly, the transmitter 66 is equipped with a control module 78 designed  
23 to provide an appropriate setpoint for the output power. The control module preferably  
24 generates the setpoint for the output power based upon a signal strength received from  
25 the target spacecraft 2, which is characteristic for the relative distance of the service ve-  
26 hicle 6 from the target spacecraft 2. Accordingly, inputwise the control module 78 is con-  
27 nected to a communication receiver 80 of the communication system 28. The receiver 80,  
28 which inputwise receives signals from the target spacecraft 2 as indicated by the arrow  
29 82, outputwise is connected to general data handling of the service vehicle 6 via a demo-  
30 dulator 84. Further components, such as a docking subsystem 86, the proximity sensor  
31 74 directly via a branch line 88, retroreflectors 90 mainly used for other spacecraft to dock  
32 on, or an optional refueling module 92 are also connected to a telecommand bus or general  
33 data handling of the service vehicle 6.

1 Beyond, the functional composition of the bus system of the service vehicle 6 comprises  
2 the following subsystems: a structure subsystem, the data handling subsystem (DHSS),  
3 an electric power subsystem (EPS), a thermal control subsystem (Ttarget spacecraft 2),  
4 an attitude orbit & control subsystem (AOtarget spacecraft 2), a telemetry tracking &  
5 control subsystem (TT&C), and a propulsion subsystem (PSS), characterized by no re-  
6 dundancy in any of the subsystems budgets.

7  
8 Albeit the fact that these subsystems are present in the majority of spacecrafts the bus of  
9 the service vehicle 6 is characterized by low capability budgets of the respective subsys-  
10 tems, in account of its mission and the lack of redundancy. The lack of redundancy is  
11 justified by the capability, in case of failure of a given fleet unit, of recovering it through  
12 another service vehicle 6 or specialized vehicle 10 and subsequently repairing it at the  
13 utility base 4.

14  
15 In particular, the EPS consists of small solar cell array panels (SAP) capable to produce  
16 part of the energy required during missions. Start of mission charging is performed at the  
17 utility base 4 before the mission starts. Likewise, the batteries of the service vehicle 6 are  
18 undersized, as at proximity to the utility base 4 the telemetry is relayed through the utility  
19 base 4, at cruise if needed directly to earth and then at approach of the target spacecraft  
20 2 through the target spacecraft 2. At proximity to the target spacecraft 2, the target  
21 spacecraft 2 is used as relay for both the TT&C and the cameras output. The EPS does  
22 not cater for any high-bandwidth link to support teleoperation or robotic facility or both as  
23 it is usually being proposed. Considering that the EPS of a typical spacecraft is 30% of its  
24 mass budget this saving is of high importance.

25  
26 The TT&C transmitter is of low bit-rate and characterized by the use of Adaptive Power  
27 Control APC. The TT&C transponders can be switched off when in proximity to the target  
28 spacecraft 2. In this case the telemetry TM and telecommand TC are transferred through  
29 the payload.

30  
31 The service vehicle 6 to perform docking and operations establishes one forward link  
32 with the teleoperators, preferably at ground control module 12, and a return link both  
33 through the target spacecraft 2.

1 The forward link is established as follows: The encoder 70 of the service vehicle 6 pay-  
2 load receives two inputs, one for the signal of the camera 72 and one for the proximity  
3 sensor 74 and generates two encoded signals for the camera signal and the proximity  
4 sensor respectively. The multiplexer 62 receives these two signals plus the encoded TM  
5 signal from the DHSS of the bus and multiplexes the three, producing a composite signal.  
6 The modulator 64 receives the composite signal, produces a modulated signal and feeds  
7 the transmitter 66 which amplifies and transmits the signal that is fed to the up-link re-  
8 ceiver of a channel of the target spacecraft 2. The target spacecraft 2 receives the signal  
9 and transmits to the ground. The transmitted signal arrives through the ground control  
10 module 12 at a Mission Control Centre (MCC) for analysis and informed action.

11  
12 The teleoperators in the MCC generate telecommands for the service vehicle 6, which are  
13 embedded within the telecommands for the target spacecraft 2. These telecommands for  
14 the service vehicle 6 are flagged with the request only to echo them and not to be exe-  
15 cuted by the target spacecraft 2. Following the reception of the telecommands the target  
16 spacecraft 2 echoes them from the telemetry channel. This signal is easily intercepted by  
17 telemetry receiver of the service vehicle 6.

18  
19 The telecommand reception is established as follows: The telemetry listen-in receiver  
20 receives the totality of the telemetry of the target spacecraft 2 and produces a signal that  
21 forwards for demodulation at the demodulator 84. After demodulation the resulting signal  
22 is forwarded to the DHSS of the bus and in particular at the application software where  
23 the analysis of telemetry is performed for extracting this information that consists com-  
24 mands to the service vehicle 6.

25  
26 The main types of operation of the service vehicle 6 in relation with a mission are cruising  
27 from the utility base 4 which is serving as a starting platform for each mission, approach-  
28 ing the target spacecraft 2 (rendezvous and teleoperation), return from the target space-  
29 craft 2 to the utility base 4, and resting at the utility base 4 until the next mission for the  
30 respective service vehicle 6 is started.

31  
32 When cruising from the utility base 4 to the target spacecraft 2 ("Cruise mode"), the serv-  
33 ice vehicle 6 travels from the utility base 4 to the target spacecraft 2 alone and autono-  
34 mously making use of the star tracker. The power output of the TT&C of the bus is ad-  
35 justed so that telemetry link can be established by the bus TT&C through either the utility

1 base 4 or the target spacecraft 2. If neither is possible due to large distances, the service  
2 vehicle 6 may be escorted in the needed part of its cruise by a specialized vehicle 10,  
3 may be used to relay telemetry and telecommands from a ground control module 12 to  
4 the service vehicle 6 and vice-versa, thus rendering the service vehicle 6 operable in any  
5 state of the cruise in spite of its limited on-board transmission and fuel capacities.

6  
7 For rendezvous and teleoperation, during the coast phase from the utility base 4 to the  
8 proximity of the target spacecraft 2 the star images from the cameras 26 are used for  
9 autonomous navigation. During the approach and rendezvous phases the service vehicle  
10 6 is controlled by means of open loop successive command cycles until docking is se-  
11 cured.

12  
13 At each command cycle the real-time output of the cameras 26 is encoded, multiplexed,  
14 and modulated together with telemetry information of the service vehicle 6 (and optionally  
15 with the output of the proximity sensor 74). The resulting signal is transmitted by the low  
16 power transmitter 66 to an up-link channel of the target spacecraft 2 through its up-link  
17 antenna. The target spacecraft 2 retransmits through the respective down link channel  
18 said signal to the ground control module 12 which may be part of a ground station (GS)  
19 and mission control center (MCC). The receiver of the ground control unit 12 receives the  
20 composite signal, demodulates and de-multiplexes and then decodes the image, telem-  
21 try and proximity sensor signals and forwards them to the MCC. The telemetry informa-  
22 tion and proximity sensor information is recorded at the MCC, analyzed and several de-  
23 rivative parameters are generated to optimize motion commands of the teleoperation ap-  
24 paratus. Said optimization compensates for fuel mass changes, sloshing activity, thruster  
25 efficiency, fuel temperature, combustion chamber temperature and other biasing factors  
26 difficult to be handled by an operator in real time. The real-time image together with the  
27 summary proximity information and other rendezvous related information (relative angles,  
28 time windows of critical steps, fuel reserves etc) is displayed onto virtual-reality head-on  
29 display systems of a plurality of teleoperators.

30  
31 Said teleoperators have control over actuators generating appropriate commands which  
32 pass through the above said optimization. Said optimized telecommands are packed in  
33 special telecommands of the target spacecraft 2 and are forwarded from the MCC to the  
34 transmitting part of the ground control module 12, encoded, modulated and transmitted as  
35 part of the telecommand stream to the target spacecraft 2 with appropriate identification.

1 The telecommands that are addressed to the service vehicle 6 are echoed by the down  
2 link (telemetry) of the TT&C of the target spacecraft 2 and listened-in by the TT&C re-  
3 ceiver of the service vehicle 6. The listened-in telemetry signal is demodulated and de-  
4 coded and a telecommand selector parses the telemetry and selects telecommands ad-  
5 dressed to the service vehicle 6. The said telecommands are executed and telemetry is  
6 generated that in turn is encoded, multiplexed with the outputs of the cameras 26 and  
7 proximity sensor 74, modulated and then transmitted to the selected up-link channel of  
8 the target spacecraft 2.

9  
10 This command cycle is repeated until the docking system 24 is securely fastened inside  
11 the combustion chamber 54 of the target spacecraft 2.

12  
13 Upon mission completion or fuel shortage, the service vehicle 6 returns to the utility base  
14 4 for resting or refueling, respectively.

15  
16 In proximity to the utility base 4, maneuvering of the service vehicle 6 is assisted by the  
17 surveillance means of the utility base 4. The service vehicle 6 assisted by the utility base  
18 4 sensors and retroreflectors performs preferably an automatic docking at the utility base  
19 4. However, teleoperated docking may also be performed.

20  
21 In the "resting mode", under service-call wait-status, the service vehicle 6 rests, preferably  
22 at the utility base 4, preferably in a storage mode that consumes very limited resources. It  
23 is envisaged that, at full deployment, there will be provided a multitude of service vehicles  
24 6 at a single utility base 4 with some variations in size and interfaces to correspond to  
25 specific types or categories of target spacecraft 2, or to better a match a selected type or  
26 level of service to be provided to the target spacecraft 2.

27  
28 In case that the target spacecraft 2 requires specific services from subsystems of the util-  
29 ity base 4 (robotic facility, ...), the service vehicle 6 may be operated to fetch the target  
30 spacecraft 2 to the utility base 4 for servicing and places back to the desired post after  
31 service ("porting mode").

32  
33 The service vehicle 6 depending of the mission duration may be equipped with additional  
34 fuel reserves and a fuel delivery subsystem. In another variation, the service vehicle 6  
35 may be designed to perform a variety of missions with add-on accessories. For example,

1 a service vehicle 6 equipped with drilling means and endoscope may be used in tandem  
2 with a specialized vehicle 10 for performing indepth investigations of failure causes or  
3 other rescue missions.

4  
5 The engine module 8 of the service vehicle 6 primarily is used for orbit maintenance of a  
6 target spacecraft 2 and for potentially reserving fuel of a target spacecraft 2. The engine  
7 module 8 comprises a subset of elements of the service vehicle 6. In particular, the bus of  
8 the engine module 8 may be part of the attitude and orbit control subsystem if the mission  
9 is propulsion only. Its payload consists of a fail-safe docking-securing mechanism identi-  
10 cal with the one of the service vehicle 6 and a TT&C that interfaces with the TT&C of the  
11 target spacecraft 2 in a way similar to the concept of the service vehicle 6. This TT&C  
12 comprises a telemetry listen-in receiver-demodulator-decoder-command selector and an  
13 encoder-modulator-transmitter that transmits to the up-link of the TT&C channel or other  
14 channel, as preferably of the target spacecraft 2.

15  
16 The engine module 8 possesses electrical and data interfaces for mating with a porting  
17 service vehicle 6, and optionally a fuel reception inlet. It disposes at all sides retroreflec-  
18 tors that facilitate automatic docking of a visiting or refueling service vehicle 6. The engine  
19 module 8 may be used to be forwarded and attached to a target spacecraft 2 by means of  
20 a service vehicle 6. When mission fuel depletes it receives additional fuel by a refueling  
21 service vehicle 6. Return to the utility base 4 may then require a porting service vehicle 6.  
22 In case of critical failure the fail-safe mechanism is automatically released.

23  
24 The level of redundancy of the engine module 8 is customizable according to mission  
25 requests. An engine module 8 for a target spacecraft 2 with no fuel reserves preferably  
26 has full redundancy. An engine module 8 for a target spacecraft 2 with fuel sufficient for a  
27 few months operation may be designed with no redundancy.

28  
29 At full-scale deployment of the servicing system 1, a plurality of utility bases 4 may be  
30 held available. The most preferable position to start with is the geostationary ring, less  
31 preferable the low earth sunsynchronous polar orbit. Any other possible orbital plane is  
32 object for positioning a utility base 4 but markets other than that of the geostationary ring  
33 and the sunsynchronous polar orbits need still to be matured.

1 The utility base 4, which is shown in Figure 5 in more detail, represents the mother ship  
2 for service vehicles 6 or other vehicles 10 of the servicing system 1. As main components,  
3 the utility base 4 comprises a main body 100, which primarily houses control systems and  
4 the like and contains the bus system of the utility base 4, an equipment/storage bay 102,  
5 a docking/refueling rack 104, and a flexible storage module 106. The interfaces between  
6 these segments dispose power, data "TMTC" and plurality of video signal connectors.

7  
8 Attached to the main body 100, primary solar panels 108 are provided for energy supply.  
9 For redundancy purposes, secondary solar panels 110 are attached to the equip-  
10 ment/storage bay 102. The equipment/storage bay 102 further carries a support grid 112  
11 for securing and storing items if needed. In order to potentially move items around, a ro-  
12 botic arm 114 preferably extending beyond the support grid 112 is mounted onto the main  
13 body 100. For establishing communication channels, a number of reflectors 116 of anten-  
14 na are attached to the equipment/storage bay 102. The primary and redundant large  
15 aperture parabolic antennas are mounted onto the down-out side of the equip-  
16 ment/storage bay 102.

17  
18 In order to allow for docking of a multitude of service vehicles 6 or specialized vehicles 10,  
19 especially for resting purposes without the need for supplying the respective vehicle  
20 further, the utility base 4 is equipped with a number of docking stations 118. Although in  
21 Fig. 5 only one docking station 118 is explicitly identified, further docking stations (pre-  
22 ferably at least four in total) are provided, preferably at least one in every main direction of  
23 the utility base 4.

24  
25 In general, the utility base 4 is characterized by a "hot redundant" architecture protecting  
26 against two points of failure of all its vital functions (links to the ground, robotic functions,  
27 docking spaces) and mechanisms (e. g. electric power subsystem, attitude control sub-  
28 system), providing survivability of itself and of the carrying fleet against double failures.

29  
30 The utility base 4 comprises means of active and passive surveillance of the surrounding  
31 space (ranging lasers, radar systems) and has active means (potentially relying on docked  
32 or otherwise available service vehicles 6) for avoiding collisions with other elements in  
33 open space (ablating laser). Given the replenishment capability of its resources through  
34 often replenishment missions and the high redundancy of its vital functions, the utility base



1 4 that is placed at the geostationary ring may in essence be the first space platform with  
2 indeterminable life span.

3  
4 It is used to perform surveillance, protection, positioning, hosting, storing, reconfiguring,  
5 repairing, converting, assembling, and science missions.

6  
7 Assuming the position of the utility base 4 at the Geostationary ring at mid day, a coordi-  
8 nate system passing from the geometric centre of its central segment is defined as fol-  
9 lows. X axis has west to east direction, Y axis has Earth to Sun direction and the Z axis  
10 has South to North direction. For the X axis also the left-right notion is used where X in-  
11 creases to the left, for the Y axis the near-far notions are used where Y increases towards  
12 far, and for the Z axis Up an-Down notions are used where Z increases towards up direc-  
13 tion. When relative reference of a segment of the utility base 4 other than the central one  
14 is made, in relation to the centre of the utility base 4, the terms IN-side and OUT-side are  
15 also used. In-side denotes the side close to the centre and out-side meaning the side of  
16 the segment at question which is opposite to the In-side at a direction departing from the  
17 centre.

18  
19 The bus system of the utility base 4 mainly consists of a double redundant TT&C sub-  
20 system, a redundant attitude and orbit control subsystem (AOCS), a redundant electric  
21 power subsystem (EPS), a redundant data handling subsystem, and a redundant thermal  
22 control subsystem (TCS). All subsystems are characterized by hot redundancy. The utility  
23 base 4 receives power primarily from the solar panels 108 (preferably three or more)  
24 mounted onto booms connected to an axial truss through mechanisms having three de-  
25 grees of freedom. The truss is characterized by passing from the geometric and momen-  
26 tum center of the main body 100 through the same axis as the robotic arm 114. The ac-  
27 tuators of the solar panel mounting mechanisms of the primary and redundant solar pan-  
28 els 108, 110 are part of the AOCS.

29  
30 The robotic arm 114 is designed to have five degrees of freedom (DOF) for the actual  
31 arm 120 and three degrees of freedom for its wrist element 122. The robotic arm 114 is  
32 dimensioned such that it can reach all upper, side and under areas of the utility base 4  
33 that may need servicing.

1 The communication system or payload of the main body 100 also possesses a redundant  
2 near range mission communication system, preferably for ten-channel RF video reception  
3 equipment, a video switch system, and a redundant communication payload, for trans-  
4 mission to the ground of four uncompressed and twelve compressed digital video signals,  
5 generated by the various surveillance and teleoperation cameras. The redundancy of the  
6 mission communication system to the ground may be provided by a specialized vehicle 10  
7 docking at the far end of the equipment/storage bay 102.

8  
9 The utility base 4 does not necessarily possess its own propulsion system, but fleet units  
10 (service vehicles 6/specialized vehicles 10) may be attached to the four sides and com-  
11 manded appropriately when needed for orbit maintenance. Attitude stability of the utility  
12 base 4 is achieved, in short time, by use of the steering mechanisms of the solar panels  
108,110. The utility base 4 is axi-symmetrically momentum stabilized.

14  
15 The flexible storage module 106 mainly consists of a flexible, inflatable, lightweight bal-  
16 loon-like surface sheet, the size and shape of which may be modified by retreating means  
17 124. In the embodiment shown, the retreating means 124 mainly are provided by con-  
18 tractable tapes which when contracted will diminish the volume of the interior of the mod-  
19 ule 106 while increasing its volume when allowed to expand. Examples for the module  
20 106 in expanded and in contracted status are shown in Figs. 6a and 6b, respectively. Ac-  
21 cordingly, the flexible storage module 106 resembles a sack-shaped flexible storage bay  
22 which possesses a plurality of ring shaped, tape-measure type tape-fastener, externally  
23 secured to the sack by means of externally to the sack secured small elliptic fasteners.  
24 Said ring tape is driven by a reel-unreel mechanism with dual reels having independent  
25 motors. By reeling-in the tape the sack closes securing the free flying objects that are  
26 placed in this sack and by unreeling the tape the sack opens to let the robotic arm 114 or  
27 other means collect the objects. Another tape fastened perpendicular to a securing ring  
28 on the external surface of the sack elongates or shortens the sack respectively, increas-  
29 ing or decreasing its volume.

30  
31 The equipment/storage bay 102, the interior of which is schematically shown in Fig. 7,  
32 and which also may be referred to as a closed equipment storage bay (CESB), is mainly  
33 used for housing equipment and material sensitive to exposure to radiation, or tempera-  
34 ture variations, or sun-rays, or small meteorites. It is where assembly, disassembly and  
35 testing takes place for small mechanical, electromechanical or electronic subsystems.

1 The treatment of the material to be handled may or may not include packaging and un-  
2 packaging in protective boxes.

3  
4 The west side of the equipment/storage bay 102 disposes a pressurization controlled pro-  
5 thalamus 130 with five outer doors 132 and a single internal door 134. The west door and  
6 inner door 134 are disposed one opposite to the other in a way to allow long objects equal  
7 to the long axis of the chamber to enter the bay in unpressurized conditions.

8  
9 The equipment/storage bay 102 possesses conditioning means for effecting and control-  
10 ling pressure, temperature and cleanliness by Nitrogen gas or other inert and non-volatile  
11 gas. It possesses permanent camera viewpoints, equipment bay for manipulation of mi-  
12 niature mechanisms and electronic circuit boards and components.

14 The up-side and down-side in the thalamus 130 for further description are defined with  
15 respect to the position of the horizontal axis, up being the position where lighting sources  
16 and gas in-jets are mounted, down being the position where gas outlets are mounted.  
17 The gas jets are spread all along ceiling and gas outlets all along floor surface. The flow  
18 of gas from up to down creates a small pressure potential to the free flying objects in a  
19 way similar to gravity.

20  
21 Manipulation of movable equipment within the equipment/storage bay 102 is performed  
22 by means of a number of three-arm small-sized robots 140 slidably and rotatably moun-  
23 ted on two horizontally secured axis 142. The long axis of the equipment/storage bay 102  
24 defines the horizontal dimension. A third axis 144 with an H profile, the profile of which is  
25 shown in Fig. 8c, is disposed in between the above two mentioned axis and disposes two  
26 conductive surfaces 146 on its interior. Said conductive surfaces 146 are used by a the  
27 robots 140 to slide along while at the same time supplying them with electric power.

28  
29 As shown in Figs. 8a, 8b in greater detail, each robot 140 consists of a pair of two co-  
30 operative human-like manipulation arms 148, each having six degrees of freedom, and a  
31 third arm 150 of three degrees of freedom that is used for stability with a two finger grip-  
32 per 152 designed to be engaged with the axis 144. Alternatively, for holding objects a  
33 three-finger gripper may be provided. The arms 148 of the robots 140 have ten finger  
34 grippers each. The robots 140 can be positioned in a face-to-face configuration for coope-  
35 rative work. The human-like arms 148 of the robots 140 can be engaged to closed-chain

kinematic configuration for manipulation of objects. This means the one arm 148 follows in tandem the movements of the other (driving) arm 148.

The robots 140 may be assisted by a plurality (minimum 2) of miniature (scale 1:3 of robots 140 or better) three arm robots 149 similar but without the sliding-rotation part of the robots 140. Mobility is provided by a sliding mechanism perpendicular to the first element of the stability arm. With small jumping movements, using the two or three arms, the robots 149 can always reach a horizontal axis, attach the sliding mechanism of the stability arm and slide along. These robots 149 either work from an axis or reach working place by a jump from the slide-on axis or are placed to workplaces by the robots 140. The robots 149 are secured, when in workplace, by means of using their stability arm (with 3 degrees of freedom). Alternatively, they can be held by the holding arm of a robot 140 for common manipulation of an object in parallel, assuming the object is secured in place by other means. The robots 149 when in workplace are connected to power/data/video-output interface and when in free float they use onboard power (batteries). Nevertheless, the floating time is limited and the respective battery size accordingly. The robots 149 dispose accelerometers and gyroscopic means for attitude control when in free floating conditions.

The equipment/storage bay 102 disposes its further elements mainly around at mid level a bench surface, filled with holes for letting air pass through and create a small virtual gravity effect, and a stiff edge for giving stability to the robots 140 when they grip on it. Disposes also a plurality of grips for securing objects in place for manipulation. It further disposes a table 154 for common, face to face manipulation with similar stiff edge, and a plurality of storage racks 156 for storing/ affixing tools, accessories, and spares. The stiff edge and other places at the racks 156 possess connectors for providing the robots 149 with power/data/video interface. The distance of the storage racks 156 allows the robots 149 to use the stability arm to attach itself to a rack 156 while the other might be engaged to fetch/store activities. For moving from one rack 156 to another the robot 149 needs to stabilize itself by using the human like arms, gripping a horizontal shelf or a number of vertical bars, or a combination of a bar and a shelf, before disengaging the stability arm to move to another shelf.

The common table 154 is surrounded by tool & parts affix area mainly for mechanical works and a tool & parts affix area mainly for electrical & electronic works.

1 The docking/refueling rack 104, which in further detail is shown in Fig. 9, is designed to  
 2 be semiautonomous and usable for all types of fleet vehicles 10, service vehicles 6, and  
 3 the like. It is provided with standardized utility outlets 160 for power, data, video, fuel, oxi-  
 4 dizer and pressurization gas. At least two of the docking positions defined by the outlets  
 5 and their respective fixation means possess also relieve in-lets for emptying the supplies  
 6 of a fleet unit. Said inlets for fuel, pressurization gas, and oxidizer are disposed symmetri-  
 7 cally to the outlets, in respect to the docking unit centre. The docking/refueling rack 104  
 8 has a plurality of pairs of docking interfaces for the fuel, oxidizer and gas tanks 162 (min  
 9 two for each species), disposed at the upper and if needed also lower sides of the same.  
 10 Each fleet unit docking position has a pair of active securing mechanisms disposed sym-  
 11 metrically to the centre of same. The tank docking positions have each a three-point ac-  
 12 tive securing mechanisms. The schematics of these locking mechanisms are shown in  
 13 Figs. 10a, 10b, which display the side surface 166 (Fig. 10a) and the upper surface 168  
 14 (Fig. 10b) of the rack 104 with the other parts (esp. tanks 162) removed.

15  
 16 All fleet unit docking positions dispose retroreflectors for aiding approach and docking.  
 17 The centre of each fleet unit docking position is hollow to allow the grapple arm pass the  
 18 rack surface and secure the position by opening the arrowheads and retracting.

19  
 20 Distributed pairs of docking positions without fuelling outlets but with data and power out-  
 21 lets are disposed at all four sides of the utility base 4.

22  
 23 The docking/refueling rack 104 is semiautonomous in the sense that it possesses a lim-  
 24 ited power supply storage system, a thermal control subsystem and a data handling sub-  
 25 system that is designed for supporting docking, fuelling operations and conditioning inde-  
 26 pendently of the main body 100. The docking/refueling rack 104 can provide, through a  
 27 data interface, to the main body 100 of the utility base 4 all locally available data.

28  
 29 A further position on the docking/refueling rack 104 is reserved for a specialized vehicle  
 30 10 which can activate its cameras when needed, to survey the docking/refueling rack 104  
 31 and the rest of the utility base 4. The video signal of the cameras can become available to  
 32 the video switch of the main body either through a video interface or via RF transmission  
 33 to the RF reception payload of the main body 100. The docking/refueling rack 104 also  
 34 possesses a redundant pressure-up equipment for helium gas which is operated only  
 35 when connected through the interface to the main body 100. This capability of autono-

1 mous operation allows for the disconnection of the docking/refueling rack 104 from the  
2 utility base 4 when deemed there is increased risk associated to performing hazardous  
3 operations such as refueling. The docking/refueling rack 104 in this case is removed by  
4 means of operating one or more fleet units and is returned back when hazardous opera-  
5 tions have been completed.

6  
7 The mechanical interface 170 that connects the dockin/refueling rack 104 to the main  
8 body 100 disposes also connectors for the realization of connecting the various interfaces  
9 of the docking/refueling rack 104 to the main body 100 (power, data, video).

10  
11 Docking of other vehicles/objects is performed through customization of extension con-  
12 structs. After a target spacecraft 2 or another floating object towed by fleet units is deliv-  
13 ered to the robotic arm 114 for stabilization, stabilization grids are erected as required for  
14 securing the object in place and release the robotic arm 114 for other activities. These  
15 grids are constructed by means of a plurality of booms that are secured along the top of  
16 the equipment/storage bay 102, by means of fasteners.

17  
18 Furthermore, the utility base 4 may be equipped with an open storage bay (OSB). Said  
19 bay is used to store equipment, tools, materials, products and spares that do not require  
20 protection or conditioning, packaged or un-packaged. It may consist of two symmetric  
21 racks, east and west, which are attached to the near side of the main body 100, through  
22 respective mechanical, electrical, data, and video interfaces. Both racks (for redundancy  
23 purposes) comprise interfaces for operating (command, data) an externally mounted de-  
24 tachable parabolic antenna each, for communication with the fleet. In the case the stabili-  
25 zation grid is deployed the redundant antenna is mounted onto the most western boom.  
26 They also both, for redundancy purposes, dispose interface for power control and video  
27 for driving a catch system as will be explained below. The two racks are stabilized by  
28 means of a bridge 172 connecting their near sides. Said bridge 172 disposes in its middle  
29 a docking station 118 for a fleet unit, preferably a service vehicle 6 or a specialized vehi-  
30 cle 10, which possesses cameras, and a shaft for mounting the catch system. The cam-  
31 eras of the service vehicle 6 or the specialized vehicle 10 can assist fetching storing op-  
32 erations of the robotic arm 114 and of the catch system. The down inner corners of the  
33 storage racks, the down near corner of the main body 100 and the down part of the rack  
34 connecting bridge 172 dispose fastening points, respectively.

1 The catch system 180, which may be placed in different positions at the utility base 4, is  
2 shown in Figure 11. Designed as a tape based capture tool (TCT), it mainly consists of a  
3 double reel-unreel mechanism 182 mounted on a 3 degree of freedom mechanism (184),  
4 two conductive tapes (186) that extend in parallel, and an end piece 188. The end piece  
5 188, which is shown in more detail in Fig. 12, is equipped with a camera, a number of  
6 light sources, a 3 degree of freedom gripping wrist 190 serving as a capturing mecha-  
7 nism. The catch system may be mounted onto a docking base sliding on a shaft attached  
8 centrally on the inside of the rack connecting bridge 172, in a way that the cameras of the  
9 fleet unit (service vehicle 6 or specialized vehicle 10) docked on the bridge 172 can su-  
10 pervise the activities of the same.

11  
12 The catch system 180 is detachable from the docking base. Similar docking positions are  
13 available at the pressurized compartment of the equipment/storage bay 102 and on the  
14 far side of the open equipment bay. The robotic arm 114 can also capture and operate  
15 the catch system 180. The end piece 188 further possesses tension sensors for each  
16 tape, gyroscopic accelerometer 192, zero to four momentum wheels 194 for attitude con-  
17 trol, RF means for transmission of the camera video signal, and a power conversion box  
18 196. The power (alternating current) arrives to the end piece 188 by means of the two  
19 conductive tapes 186. It is converted to appropriate voltage ratings and distributed where  
20 needed. Control signals arrive to the end piece 188 by means of modulating the alternat-  
21 ing current transported through the tapes 186. Video link is transmitted from the end  
22 piece 188 by means of an RF transmission. The RF signals are received by a central RF  
23 reception base.

24  
25 Small and medium volume objects for storage may be placed into boxes and boxes are  
26 secured in a set of adjacent shelves of parallelogram shape of various sizes assembled  
27 out of aluminum or carbon fiber elements or other strong lightweight material. Said  
28 shelves may comprise a plurality of temporal adhesive tags at their bottom side that se-  
29 cure boxes when in place, even if a plurality of small boxes is stored into a large shelf.  
30 The fetching and storing of objects is performed by means of the robotic arm 114, the  
31 catch system 180, or other.

32  
33 The upper side door 132 of the pro-thalamus 130 (Fig. 5) is reachable by the robotic arm  
34 114 and two appropriately positioned catch systems 180. All 5 outer doors 132 have ma-  
35 tching interfaces for extension modules. The pro-thalamus 130 houses a round rotating

1 plate equipped with a catch system 180 in the one side of the table, which table can be  
2 raised, when an outer door 132 of the pro-thalamus 130 is open, above the upper surface  
3 of the equipment/storage bay 102. This way, an object that has been placed on the pro-  
4 thalamus table with the help of the catch system 180 can become available to the outside  
5 and vice-versa. The catch system 180 can also make available objects to the interior of  
6 the main thalamus of the equipment/storage bay 102 when inner door of pro-thalamus  
7 130 is open.

8  
9 In general, the fleet units of the servicing system 1, in particular the service vehicles 6, do  
10 not have redundancy or means for significantly reconfiguring themselves, as regards their  
11 hardware. Reconfiguration, repairing, assembling, upgrading is performed at the utility  
12 base 4 using special purpose facilities. In addition, the upgrading subsystem is used for  
13 conversion of captured foreign objects (CFO). Said CFOs that are of main interest for  
14 conversion are non-functional satellites, tanks from spent upper stages, and the like.

15  
16 The upgrading subsystem comprises at least: an open equipment bay (OEB) and a pro-  
17 tected, or closed equipment-storage bay 102 (CESB). Said OEB is mounted at the far  
18 side of the main body 100, through a mechanical electrical and data interface and the  
19 CESB is housed in a nitrogen gas pressurized chamber mounted at the west side of the  
20 main body 100.

21  
22 Said Open Equipment bay "OEB" is used for mechanical or electrical works on the fleet,  
23 target spacecraft 2s, or CFO. Conversion operations, be between else processes for ef-  
24 fecting access windows on tanks, pipe connecting / disconnecting, rack mounting, equip-  
25 ment and cabling network installation.

26  
27 Said OEB possesses a plurality of (minimum two) of human size dual robotic arms (pri-  
28 mary and redundant) for tool / manipulation with ten finger grips, and arm articulation si-  
29 milar to the human (six degrees of freedom). Said dual robotic arms are movable on top  
30 of the main body 100 and OEB by means of a mobile base that slides onto a T shaped  
31 rail path mounted on their surfaces. The rail path starts at the near edge of the upper  
32 surface of the main body 100, crosses the upper surface of the main body 100 with direc-  
33 tion towards the OEB. It passes at a sufficient distance from the centre of the main body  
34 100 where the robotic arm 114 is mounted. Said rail path then crosses the OEB in a pa-



1 rabolic shape and then passes on top of the CESB having a mounting point on it and  
2 continuing in a hemicyclic shape arriving to the upper side of the storage rack.

3  
4 Each robotic mobile base is driven by four powered wheels mounted on axis parallel to  
5 the rail shaft and pressing against said T rail shaft. Six ball bearings for sliding along the  
6 rail head are provided as well as four short ones mounted just below and two wide ones  
7 above the T rail head, mounted in parallel to the said horizontal T rail head.

8  
9 OEB also possesses a plurality of tools and benches for performing the said services si-  
10 milar to what is found in the Ground Segment Support equipment and particularly those  
11 that can be exposed to the open space environment with limited shielding.

12  
13 The utility base 4 has a stock of accessories for repairing & upgrading the fleet and own  
14 subsystems.

15  
16 These accessories between else include replacement modules for the hot redundant ele-  
17 ments of the utility base 4, (EPS, AOCS, MCP, RF, TT&C) telecommunication modules  
18 for UHF and S band and data channel telecommunication modules for C, Ku and Ka band  
19 of various output power ratings. They further include attitude control sensors (sun, earth,  
20 star based), cameras of various aperture ratings, filters, lenses, endoscopes and telesco-  
21 pic probes, towing tethers tether/wire deployment/retracting add-on module as well as  
22 sets of retroreflectors, laser diodes, motors, ball bearings, lubricants and lubricating me-  
23 ans. Adhesive materials, insulated wires, solar cell spares and fly wheel spares, valves  
24 and pipes, thrusters and any other accessory that may be foreseen, need assessment  
25 based on a statistical estimation of failure risks of the target spacecraft 2 components and  
26 subsystems.

27  
28 Said repairing and upgrading tools comprising, between else, of hardware tools set, (la-  
29 the, aluminum soldering, etc), electrical tools set (wire connectors, soldering etc), electro-  
30 nic tools set (polymeters, palmographs etc.)

31  
32 A plurality of tether equipped truss assists in the disassembly process by displacing dis-  
33 assembled elements away of the OEB core. Each time a disassembled element is at-  
34 tached to the tether the tether is promoted proportionally to the size of the attached ele-

1 ment. To fetch a stored element from the tethered truss the tether is advanced or re-  
2 tracted accordingly.

3  
4 The utility base 4 also is equipped with active and passive surveillance means.

5  
6 These means are used for accurate positioning of objects in the surrounding space and  
7 for protection from space debris as well as for assisting cruise or automatic docking of the  
8 fleet units. The proximity radar provides a coarse but wide image of the surrounding  
9 space objects and the ranging laser a precise determination of distance and position of  
10 objects in the surrounding space. The ablating laser destroys small objects or alters the  
11 trajectory of larger objects to avoid collision with target spacecraft 2 or utility base 4 or  
12 fleet units. It also destroys or steers the particles that escape from the manufacturing pro-  
cesses to a desired collection point.

14  
15 The utility base 4 requires numerous video and Telemetry links to be established for full  
16 operation. A gradual process is envisaged to provide the required bandwidth with use also  
17 of a resurrected satellite.

18  
19 The specialized vehicle 10 may be designed to perform several functions of a so-called  
20 escort agent (EA). It basically has the same functional elements in its bus as a typical  
21 service vehicle 6 but reinforced in terms of EPS budget and size. It is mainly used for  
22 missions with FCO and non-cooperative target spacecraft 2, or with target spacecraft 2  
23 where compatibility with its payload has not been achieved.

24  
25 Its payload consists of two steerable high gain antennas, for establishing receiving link  
26 and retransmitting link to different directions, and cameras. It is designed to assist the  
27 docking and other services of a service vehicle 6 by establishing the required surveillance  
28 and teleoperation video links with a ground control unit 12 directly or through the utility  
29 base 4, or through a third spacecraft. It receives through RF video and TTC signals from  
30 a service vehicle 6 or directly from its own cameras and retransmits after amplification.

31  
32 A type of escort agents with refueling capability is defined for refugee rescue missions or  
33 other high energy orbit missions.

1 The primary operational concept for the servicing system 1 is to reuse the service ve-  
2 hicles 6 and other elements of the system in many missions, servicing satellites that are  
3 far away in terms of delta velocity potential required to reach them and carry them or  
4 maintain their orbit or optimize their trajectory, in particular by using the target spacecraft  
5 2 for relaying signals to ground control.

6  
7 Nowadays, most of the satellites are operating in the C, Ku and Ka bands. Constructing  
8 communication means of very low power in a wide part of these bands to allow compati-  
9 bility with a large population of satellites is not a problem. In addition to that, the utility base  
10 4 comprises means for performing extensive reconfiguration and communication module  
11 exchanges so that the service vehicle 6 can become compatible with almost the totality of  
12 the current satellite population. Since in short distances of a few meters to hundred me-  
13 ters away from the target spacecraft 2, the service vehicle 6 will have to operate the said  
14 link, directionality of the antennas is not that important and that there are backwards  
15 electromagnetic wave lobes that can be exploited for this cause.

16  
17 The advantage of the method is the provision of the needed bandwidth with extremely low  
18 powered means. In the case where the powerful communication means of the target  
19 spacecraft 2 are used as relay means, the means required in the ground for reception of  
20 the service vehicle 6 is as simple as a simple TV receiver in the case of TV satellites.

21  
22 Alternatively as it is foreseen in the case where the target spacecraft 2 can not provide  
23 the required transmission means another specialized vehicle 10 will perform the task of  
24 establishing the link to the ground directly or through a relay, acting as relay satellite in  
25 the very vicinity. In this case it might also observe the service vehicle by its own means  
26 and provide alternative or the only view point of the service provision to the ground con-  
27 trollers.

28  
29 The utility base 4, or a third satellite can serve as relay points, but these constitute less  
30 preferred options.

31  
32 When the service vehicle 6 is in close proximity to the target spacecraft 2 even the tele-  
33 metry / telecommand link can be performed through the target spacecraft 2. The method  
34 for receiving telecommands at the service vehicle 6 in this case is by listening to the tele-  
35 metry of the target spacecraft 2 and select those packets that will be properly identified

1 that are addressed to the service vehicle 6. This will further reduce the energy waste and  
2 increase the comfort of the target spacecraft 2 operators.

3  
4 Apart from the cases where the service vehicle 6 will act alone or with the help of a ser-  
5 vice vehicle 6 a set or behaviors is designed to capitalize on the fact that a plurality of  
6 them will be available.

7  
8 A method for reaching a signal from a remote place back to the utility base 4 or elsewhe-  
9 re can be performed by placing a plurality of service vehicle 6 in distances according to  
10 their respective telecommunications means and effect the transmission by means of re-  
11 laying from one to the other the signal until it reaches the destination.

12  
13 A service vehicle 6 also can carry other service vehicle 6 (towing pushing) docking side by  
14 side.

15  
16 A set of service vehicles 6 can add on their thrust power and perform a relocation missi-  
17 on.

18  
19 A set of service vehicles 6 can add their reception transmission means in a formation of a  
20 large phased antenna array by positioning themselves according to the desired source of  
21 signal or target and coordinated by means of a special Escort agent of the utility base 4 to  
22 operate on this mode.

23  
24 Several functions may be automated. Most importantly, the docking operation to the utility  
25 base 4 and the docking operation to the Engine Module. Advantage of both is the reduced  
26 need for teleoperators and resources to establish the video and control link.

27  
28 In the case of the docking to engine module or other service vehicle 6 or specialized ve-  
29 hicle 10 which is far apart from the utility base 4 the additional advantage is the autonomy  
30 achieved. It can be planned at any time. Low level of resources required as docking is  
31 performed with optimum fuel usage and provides high level of confidence to the owners of  
32 the target spacecraft 2.

33  
34 A currently preferred embodiment of the service vehicle 6 is a canonical (rectangular,  
35 pentagonal, hexagonal, ) rod shaped structure covered with solar panels. In another em-

1 bodiment a pair of solar panels shall be deployable and retractable. When the panels are  
2 retracted and secured on the service vehicle 6 surface the service vehicle 6 can be navi-  
3 gated as a spin axis stabilized spacecraft. The solar panels will be deployed mainly after  
4 docking to a target spacecraft 2 to extend beyond the shade of the satellite that is ser-  
5 viced. The service vehicle 6 will have the main thruster in its bottom side while at the top  
6 side will have the simple grabble mechanism to grabble the target satellite by the interior  
7 of the fuselage.

8  
9 The one side of the service vehicle 6 will be capable of performing docking to the utility  
10 base 4 or to an Escort vehicle 10 for refueling. The docking and refueling mechanism will  
11 be positioned to lower half part of the service vehicle 6 so that the refueling can be possi-  
12 ble even if the service vehicle 6 is attached to a target spacecraft 2.

13  
14 The service vehicle 6 will be passive as regards the mechanism for the refueling docking  
15 but with adequate passive targeting aid (laser retro-reflectors) to ease proximity and semi  
16 or fully automated docking. The service vehicle 6 will benefit from the stability of the  
17 common docking place. In this way they will be able to switch most of their equipment  
18 (momentum wheels, communication payloads, thermal subsystem saving), reducing their  
19 wear and increasing their lifetime (form 100% up to 1000%). There will be economy of  
20 resources. Fuel consumption reduced to zero, power consumption will be reduced to 2%.  
21 The proximity of the service vehicle 6s one to the other can reduce heat dissipation.  
22 Further economy. The proximity of the service vehicles 6 can provide inter-alia protection  
23 against debris.

24  
25 The service vehicles 6 can benefit from a deep-storage mode where some elements  
26 could even be extracted for placement under special conditions for extending their lifeti-  
27 me. The battery can be stored separately form the service vehicle 6 in appropriate condi-  
28 tions. The fuels can be flushed out to avoid corrosion of tanks, pipe lines, valves and  
29 other elements form leaks. The tanks could be depressurized to reduce mechanical  
30 stress from pressure. The service vehicles 6 can benefit from service vehicle 6-to-Client  
31 interface reconfiguration available at the utility base 4. The service vehicle 6 will be re-  
32 ceptive to interface configuration changes. It will be possible to change the Communica-  
33 tions payload and the grabble mechanism to customize according to client characteristics.  
34 The service vehicle 6 can benefit from service vehicle 6 to ground interface reconfigurati-  
35 on service available at the utility base 4. The utility base 4 will have the capability to

1 change the configuration characteristics of the service vehicle 6 Interface to the utility  
2 base 4. The communication payload may be adjusted depending on the required down  
3 link to be used through an Escort-service vehicle 6, through the utility base 4 or through  
4 the target spacecraft 2 or otherwise.

5  
6 The service vehicle 6 can benefit from mission dependent reconfiguration. The optimum  
7 reusability and efficiency will depend on this capability of the utility base 4 to provide this  
8 type of reconfiguration. For each mission the fuel reserves will be adjusted, the communi-  
9 cation payload will be reconfigured. Transceivers of appropriate strength will be installed  
10 and other characteristics will be adjusted (momentum, thruster position)

11  
12 When a given spacecraft is close to another spacecraft it can capture the telemetry pro-  
13 duced by the first said spacecraft by very simple means as the transmission takes place  
14 customarily with a unidirectional antenna and at power levels sufficient to reach earth.

15  
16 The telemetry information is transmitted into standardized packets and usually consists of  
17 acknowledgments of commands, parameter values from various sources, memory dumps  
18 and simple echo messages. A number of these telemetry data packets and specifically  
19 these whose content can be forced to particular content by telecommands (like echo te-  
20 lemetry, or memory dumps of certain areas) can be selected to carry command data that  
21 are addressed to another spacecraft in the range of the telemetry of the first spacecraft.

22  
23 This method invented can be used by any spacecraft that can listen-in to the telemetry of  
24 the first said spacecraft.

25  
26 The method is proposed to be exploited by the plurality of apparatuses here invented and  
27 intent to offer services to target spacecraft 2.

28  
29 This method, provides merit form the technical and economic point of view. The means  
30 used for the first satellite to perform the telecommand link are reused at no extra cost by  
31 a plurality of other satellites in a master-slave configuration..

32  
33 Additional merit of the invention in the case where the method is applied to control plural-  
34 ity of servicing satellites is the assurance provided to the target spacecraft 2 owner that

1 no dangerous commands may be sent to the plurality of the servicing vehicles. He will  
2 have full visibility and control to the operations of the servicing vehicles.

3  
4 The method is applied by the current invention to make economies in the telecommand  
5 reception means and power consumption and to reinforce the confidence to the target  
6 spacecraft 2 owners that they have full control of the process. Method of recovering te-  
7lemetry information from a satellite whose telemetry means transmit at very low power  
8 output or buffering is required or encrypting the telemetry information is required.  
9 It is desired in certain circumstances to listen from close distance to the telemetry infor-  
10 mation of the target spacecraft 2 either because the telemetry transmission means can  
11 not produce a high power signal, either for power constraint/preservation reasons or be-  
12 cause of problems in the telemetry transmission means.

14 Additional reasons for listening in can be the need to store the telemetry for transmission  
15 at a later time. This is especially useful to low earth orbiting satellites that circulate earth  
16 and therefore are not all the time in the field of view of a ground station.

17  
18 Still another reason is the possible need to encrypt the telemetry before transmission,  
19 need that became apparent after the design phase of the target spacecraft 2.  
20 In all the above circumstances it will be beneficial to provide a means of retransmitting the  
21 telemetry of a target spacecraft 2 at another frequency and at higher power or with a de-  
22 lay or in encrypted mode or in any combination of the above.

23  
24 The proposed method of invention is the delivery of a service vehicle 6 equipped with the  
25 appropriate listen-in, possible buffering, possible encryption and retransmission means  
26 preferably to an up-link channel or directly to the ground.

27  
28 The choice of way of establishing the feed link depends on the availability of the said up-  
29 link. If the direct link is the choice appropriate modification of the standard service vehicle  
30 6 shall be performed before mission starts at the utility base 4. The appropriate modifica-  
31 tions shall include above standard power generation means, power conditioning means  
32 and telemetry retransmission means.

33  
34 An uncontrollable target spacecraft 2 that tumbles is very difficult and dangerous to cap-  
35 ture because it may damage the spacecraft that attempts approach for the capture.

1 A new method is proposed for stabilizing a tumbling spacecraft as follows:

2  
3  
4 A pair or service vehicles 6 is equipped with an add-on dual wire deployment / retracting  
5 system (WDRS), secured in their lower part of one of their sides. Each of the said  
6 WDRSs are equipped with a camera or the pair of service vehicle 6 is escorted by an  
7 Escort service vehicle 6 with camera and telecommunication means. The length of the  
8 wire (rolled in the said WDRS) shall be several hundred meters in order to allow operation  
9 of the escort service vehicle 6 without risk of contamination against the target spacecraft  
10 2. The middle of the wire is equipped with a multi anchor apparatus or a net or simply a  
11 loop, whatever the case defines as more appropriate that would capture the SC if comes  
12 to its path.

13  
14 Formation flying of the pair of the service vehicles 6 in proper angle shall enable the tum-  
15 bling target spacecraft 2 to be captured. Depending on the moment of inertia of the target  
16 spacecraft 2, the service vehicles 6 shall perform well timed, directed and weighted  
17 thrusts against the force the wire will effect as it folds around the tumbling spacecraft. A  
18 third service vehicle 6 shall observe closely the whole operation. It shall ease the target-  
19 ing of the wire capture and determine the risk of damage to the spacecraft after the cap-  
20 ture is achieved to direct properly the tumbling attenuation operation.

21  
22 In some cases, the transportation of a target spacecraft 2 to higher latitudes, if it has  
23 been stacked below the required altitude, or need to go to far longitudes, or need to im-  
24 plement a high inclination correction or for other reasons, requires high acceleration- de-  
25 celeration maneuvers.

26  
27 The said transportation requires stability of the solar panels to avoid deformation or dam-  
28 aging them, and to avoid destabilizing libration of the said solar panels during accelera-  
29 tion-deceleration phases of the said transportation mission.

30  
31 A simple, low material requiring method, is envisaged in order to secure the solar panels  
32 from deformation and libration caused by said acceleration/decelerations of the said  
33 transportation mission  
34



1 A plurality of service vehicles 6 (minimum one, preferably two, more preferably three,  
 2 most preferably five) equipped each with a wire deployment & retracting system in one  
 3 side and a sidewise gripe on their front side and a plurality (zero or more) of Engine Mod-  
 4 ules is deployed. The said Engine modules secure themselves with the help of the said  
 5 plurality of service vehicle 6 to the fuselages of the said target spacecraft 2. Then, each of  
 6 the service vehicle 6 in turn secures at the EMs the tip of a wire protruding from the said  
 7 wire deployment / retracting system. The said service vehicle 6 capture the solar arrays  
 8 from their tips at the two ends in a manner that the axis of the body of the said service  
 9 vehicle 6 is perpendicular to the panel surface. After securing the grips the wire retracting  
 10 systems retract the wires forcing the tips to stability and pressing the lower part of the  
 11 Engine Module / service vehicle 6 against the said target spacecraft 2. In this configura-  
 12 tion the service vehicle 6 that are attached to the panel tips can perform thrusts, of which  
 13 thrusts the vertical component vector of force is effected mainly to the base of the Engine  
 14 Module and partly to the stiffened solar array panels. Advantageously, the distribution of  
 15 the force in the three extreme points of the transported body gives excellent moment of  
 16 inertia and steering capabilities.

17  
 18 Steering of the panels can add to the maneuverability of the system.

19  
 20 The thrust history of all thrusters in the system will be archived together with loads (wet or  
 21 dry), attitude and gyroscopic information, internal acceleration measurements and accel-  
 22 eration measurements as externally observed by laser ranging from the utility base 4. The  
 23 totality of this information will be analyzed after every mission and new calibration pa-  
 24 rameters will be made available. The same parameters minus the ranging information  
 25 (when away from the utility base 4) will be monitored real time by the thruster owning ob-  
 26 ject for updating the relative efficiency thruster table.

27  
 28 For the mass calculation the following method applies when measurement takes place  
 29 away from the utility base 4. A service vehicle 6 with recently calibrated thrusters attaches  
 30 to the target spacecraft 2. The solar panels of target spacecraft 2 are secured in the most  
 31 stable way. A plurality of EA with cameras and ranging lasers position themselves in the  
 32 space in front of the target spacecraft 2 a little above and a little below its expected tra-  
 33 jectory at a distance appropriate for the laser means. They point the laser beams towards  
 34 the target spacecraft 2 and body and they take measurements during a smooth gradual

1 acceleration phase until a few seconds after stopping acceleration. The acceleration shall  
2 be smooth and gradual in order to minimize the sloshing of the dry mass.

3  
4 The analysis of thrusts data, ranging data, visual data, and simulation analysis on ground  
5 can give accurate estimation of the total mass and wet mass specifically.

6  
7 The deployment of the servicing system 1 is proposed to start with the launch of a single  
8 service vehicle 6 that will make use of the target spacecraft 2 as a relay point therefore  
9 not needing neither escort service vehicle 6 for the HBTL nor utility base 4. It may be fol-  
10 lowed by one or more service vehicle 6 and/or by an escort service vehicle 6 with refuel-  
11 ing capabilities. The refueling escort –service vehicle 6 will provide the required fuel re-  
12 serves for the current and part of the upcoming fleet. A possible further refueling escort-  
13 service vehicle 6 may precede the arrival of the utility base 4.

14  
15 Advantages of this deployment plan is the low initial cost and the high final functionality.

16  
17 Three deployment areas are foreseen in the beginning

- 18  
19 ■ The Geostationary ring  
20 ■ The Low earth orbiting satellites  
21 ■ The Medium Earth orbits

22  
23 The invention is presented to start providing service in the geostationary ring but the  
24 similar apply for the lower to earth orbits and to further missions around other celestial  
25 objects or to trajectories between celestial objects.

26  
27 This split of functionality between utility base 4, service vehicle 6, EM and EA provides for  
28 low mass, low cost, high fuel/dry mass ratio, high maneuverability, long range and oper-  
29 ating duration in the service vehicle 6, EA and EM part. On the other had the utility base 4  
30 gives to the system high reusability, maintainability, multiple uses, elimination of waste.  
31 The system in total provides for efficient, reliable and low cost service operations.

32  
33 Main advantage of this architecture is that the service vehicle 6 results in an extremely  
34 low dry mass, low cost, agile spacecraft that can service target spacecraft 2 which require  
35 large delta velocity potential. Yet main advantage of this element of design is that a dual

arm robotic facility is also made available in the context of the system (through the utility base 4 component) allowing for extensive servicing operations.

A particular advantage of this configuration is that the service vehicle 6 is released by the highly demanding subsystem budgets (performance characteristics), required for a link with earth, which are required only for a small fraction of the lifetime of the service vehicle 6 while in the rest of the life time represent dead mass (large overhead in maneuvers). Placing this functional requirement to another element of the system that does not perform demanding maneuvers (to the utility base 4) it gives high flexibility and low construction and operational costs at the service vehicle 6 part. This fundamental characteristic of the design of the service vehicle 6 is new, unique and useful.

The service vehicle 6 does not need to have redundancy of most of its sub-systems (power, solar, propulsion). Its only safety characteristic will be that it will have fail-safe mechanism of its grabble. The service vehicle 6 will capitalize on the presence of utility base 4 in the relative proximity and also of the similar service vehicle 6 that will be able to perform a rescue operation with target the failed service vehicle 6.

Special Escort-service vehicle 6 will have capability to refuel other service vehicles 6.

Advantages are: A service vehicle 6 can perform of a heavy mission (high delta velocity) without having to return to the Utility base for refueling and performing again the rendezvous with the serving spacecraft (mostly manual and difficult task). Instead it can remain attached to its mission and wait for successive installments of fuel by a refueling service vehicle 6 (depending on availability). In this way the required wet mass at the beginning of its mission can be very limited facilitating the rendezvous and docking as well as reducing the cost of orbit maintenance. In the occasion the mission finally required replenishment of the fuel this is achieved by the special Escort-service vehicle 6.

If a service vehicle 6 runs out of fuel the Escort-service vehicle 6 can replenish and then either separate or perform flight attached one to the other reducing the risk in case of failure of one of the two. The special-service vehicle 6 in the beginning of the deployment of the system may substitute the utility base 4.

1 The service vehicle 6 will take advantage of the capabilities of the utility base 4 to perform  
2 reconfiguration operations. It will be able to change communication payload and grabble  
3 characteristics in order to fit for service for a variety of potential target spacecraft 2.

4  
5 The service vehicle 6 shall be able to enter an idle storage mode when docked on the  
6 utility base 4 or to another service vehicle 6. This will conserve the wear of most subsy-  
7 stems even the structure (by thermal cycles) and reduce the consumption of energy. This  
8 will become possible by the presence of the utility base 4 or an Escort-service vehicle 6.

9  
10 A simplified version of the service vehicle 6 is the Engine Module that does not have ca-  
11 meras and the like for performing a navigation and docking. Is put in place on an target  
12 spacecraft 2 with the help of a service vehicle 6 or EA and remains there to perform stati-  
13 on keeping and inclination maneuvers until it will require fuel replenishment. In this case,  
14 a service vehicle 6 with capability of automatic docking on the Engine Module will dock  
15 and provide fuel for another term of the mission.

## Reference Numerals

1	servicing element
2	target spacecraft (Utility Agent, UA)
4	utility base
6	service vehicle
8	engine module
10	specialized vehicle
12	control module
14, 16	arrows
20	main body
22	propulsion system
24	docking system
25	exhaust system
26	cameras
28	built-in communication system
30	control system
32	dashed line
34	receiver
36	emitter
38	arrow
40	hollow axle
42	action axle
44	fail-safe mechanism
46	double arrow opening tip
48	surface
50	nozzle ring
52	exhaust channel
54	combustion chamber
60	communication module
62	multiplexer
64	modulator
66	transmitter
68	controller module
70	encoder

72	camera
74	proximity sensor
76	arrow
78	control module
80	receiver
82	arrow
84	demodulator
86	docking subsystem
88	branch line
90	retroreflectors
92	refueling module
100	main body
102	equipment/storage bay
104	delivery/refueling rack
106	storage module
108	primary solar panels
110	secondary solar panels
112	support grid
114	robotic arm
116	reflectors
118	docking station
120	actual arm
122	wrist element
130	pressurization controlled prothalamus
132	outer doors
134	internal doors
140	three-arm small-sized robots
142	horizontally secured axis
144	axis
146	conductive surfaces
148	human-like manipulation arms
150	arm
152	two finger gripper
154	table
156	storage racks

160	utility outlets
162	tanks
166	side surface
168	upper surface
170	mechanical interface
172	bridge
180	catch system
182	double reel-unreel mechanism
184	freedom mechanism
186	conductive tapes
188	end piece
190	gripping wrist
192	gyroscopic acceleraometer
194	momentum wheels
196	power conversion box

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## Claims

1. Service vehicle (6) for performing in-space operations on a selected target spacecraft (2), comprising a communication module (60) which with respect to its transmission characteristics is configurable in order to meet given receiver parameters of said selected target spacecraft (2).
2. Service vehicle (6) according to claim 1, wherein said configurable communication module (60) comprises a transmitter (66).
3. Service vehicle (6) according to claim 1 or 2, further comprising a control module (68) for providing a setpoint for an output power of said configurable communication module (60).
4. Service vehicle (6) according to claim 3, wherein said control module (68) inputwise is connected to a first position sensor, said first position sensor delivering a set of data characteristic for the current position of said service vehicle (6).
5. Service vehicle (6) according to claim 4, wherein said control module (68) inputwise is connected to a second position sensor, said second position sensor delivering a set of data characteristic for the current position of said target spacecraft (2).
6. Service vehicle (6) according to one of the claims 3 through 5, wherein said control module (68) inputwise is connected to an orientation sensor, said orientation sensor delivering a set of data characteristic for the current orientation of said target spacecraft (2) in relation to said service vehicle (6).
7. Service vehicle (6) according to one of the claims 1 through 6, further comprising a docking system (24), said docking system (24) comprising a hollow first axle (40) insi-



de of which a second axle (42) is moveably disposed, said second axle (42) carrying an activateable arrow tip (46).

8. Service vehicle (6) according to one of the claims 1 through 7, further comprising means for identifying said target spacecraft (2).

9. Servicing system (1) for providing in-space service operations to a selected target spacecraft (2), comprising a service vehicle (6) according to one of the claims 1 through 8, and further comprising a ground control module (12) for delivering operational commands to said service vehicle (6).

10. Servicing system (1) according to claim 9, wherein said ground control module (12) is set up to receive data from said service vehicle (6) by using said target spacecraft (2) as a relay station for signals emitted from said service vehicle (6).

11. Servicing system (1) according to claim 9 or 10, further comprising an orbit-based utility base (4) for said service vehicle (6).

12. Servicing system (1) according to one of the claims 9 through 11, further comprising a relay module for forwarding transmitted signals to said service vehicle (6).

13. Method for in-space servicing of a selected target spacecraft (2), wherein a service vehicle (6) according to one of the claims 1 through 8 is used to perform selected in-space operations on said target spacecraft (2), and wherein operational signals from said service vehicle (6) are transmitted to a ground control module (12) by using said target spacecraft (2) as a relay station for said operational signals.

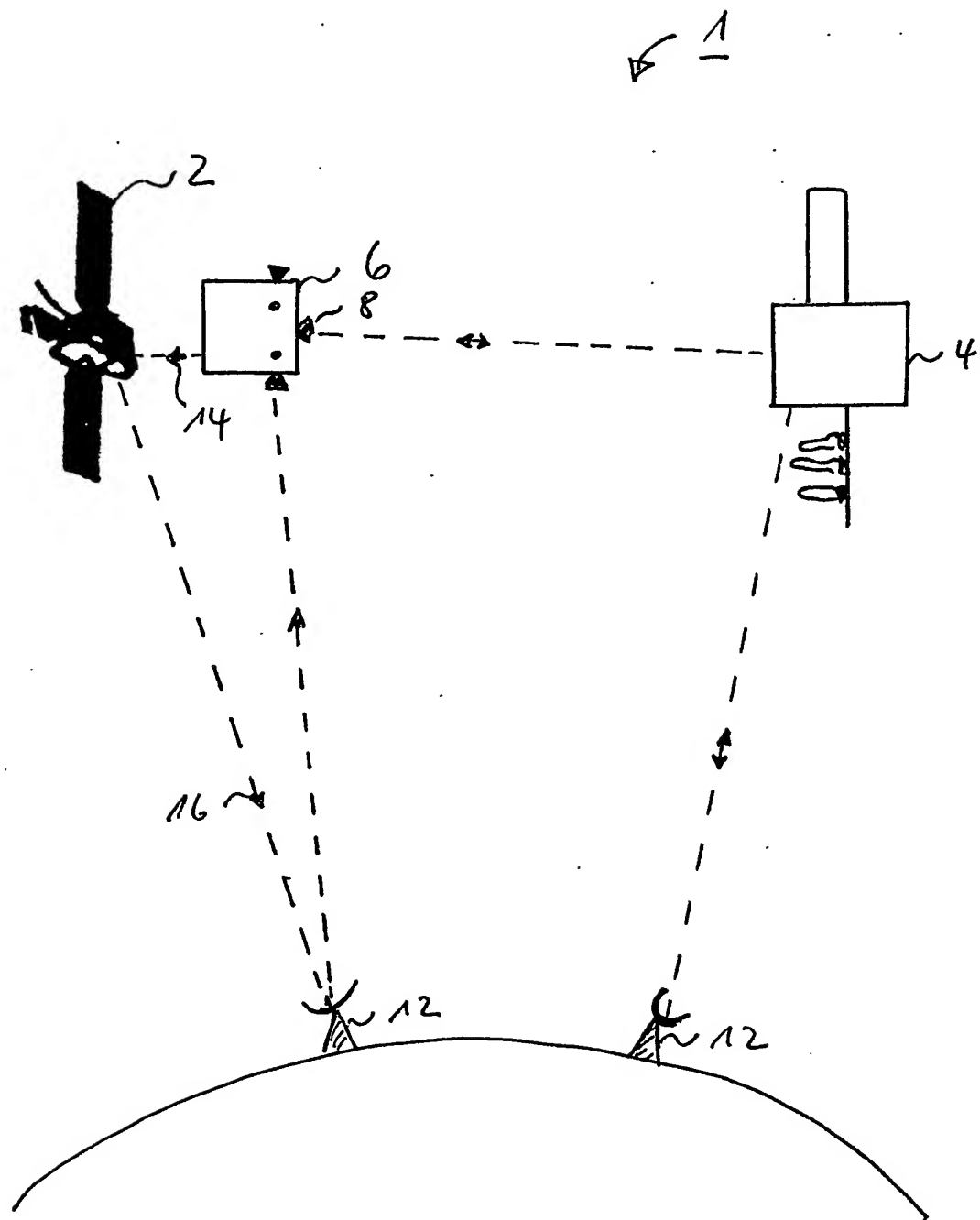
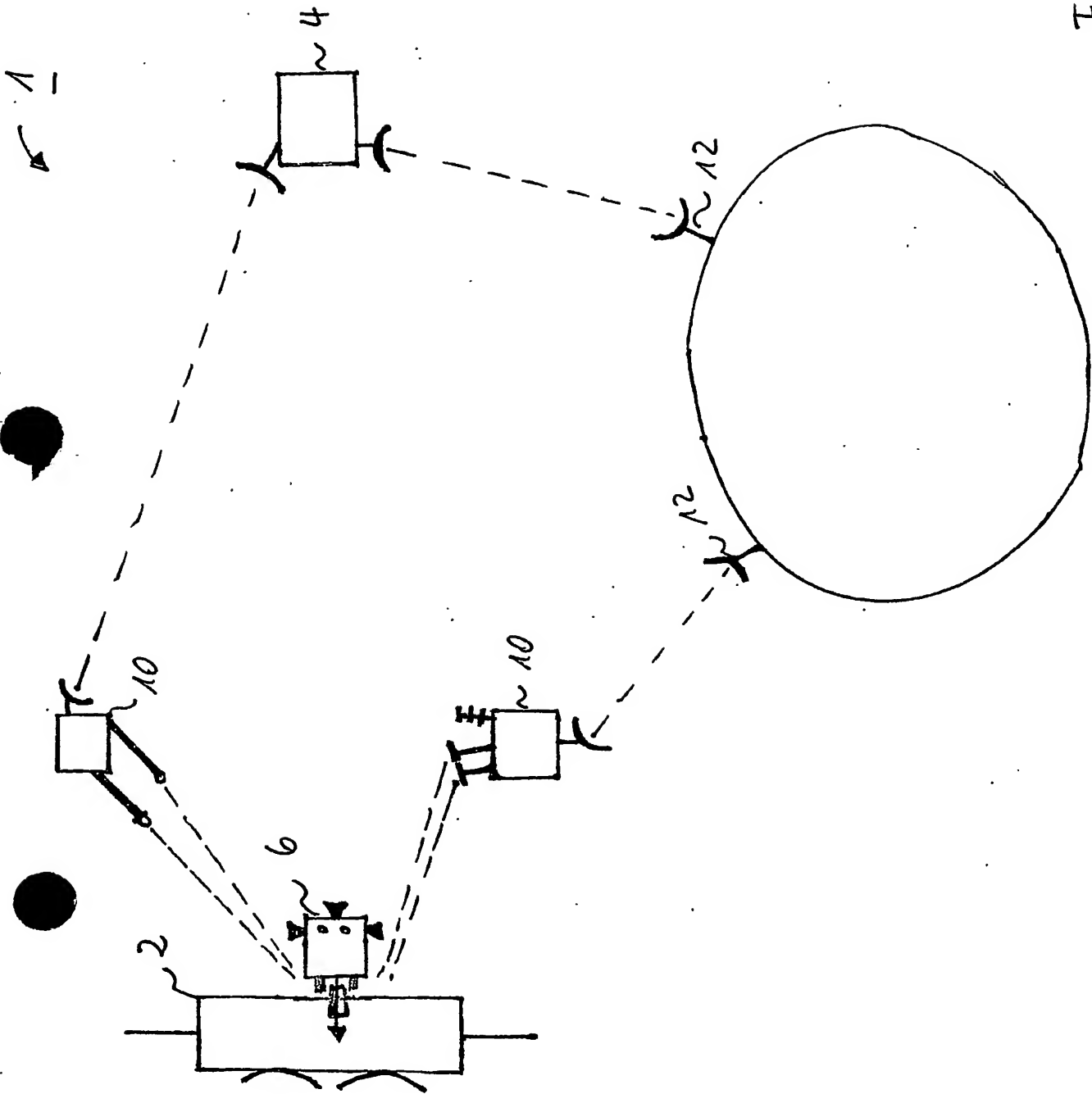


Fig. 1

Fig. 2



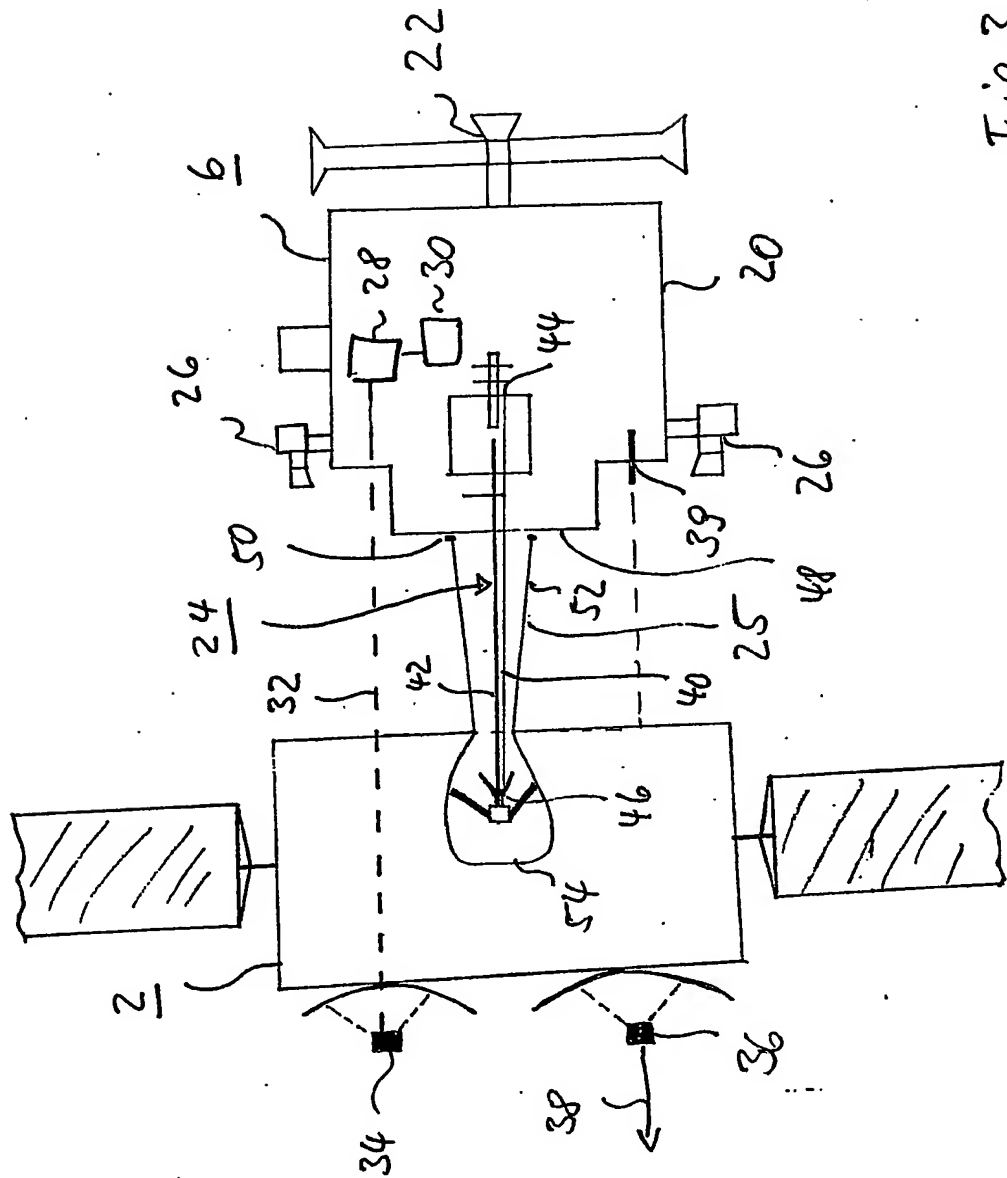


Fig. 3

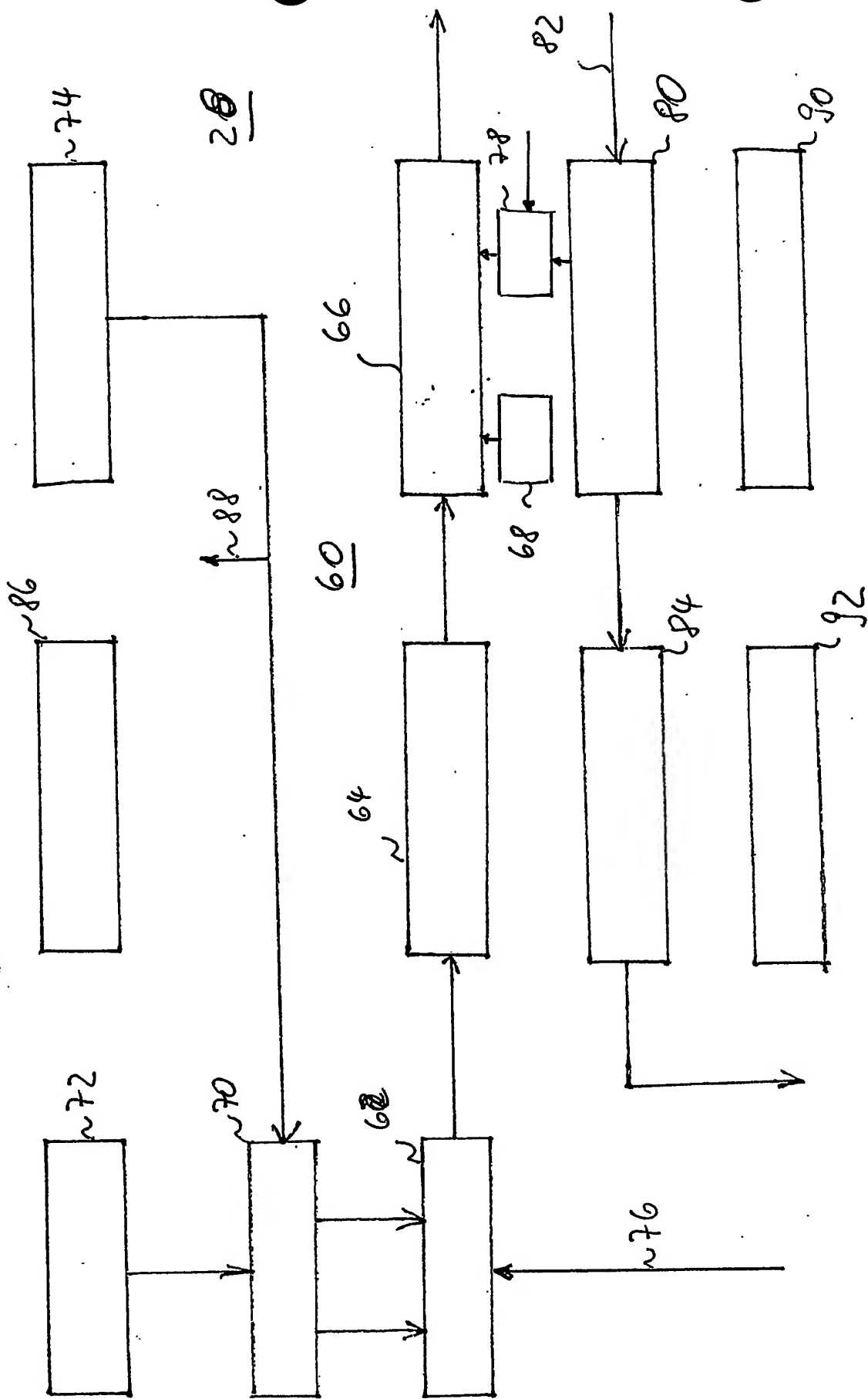
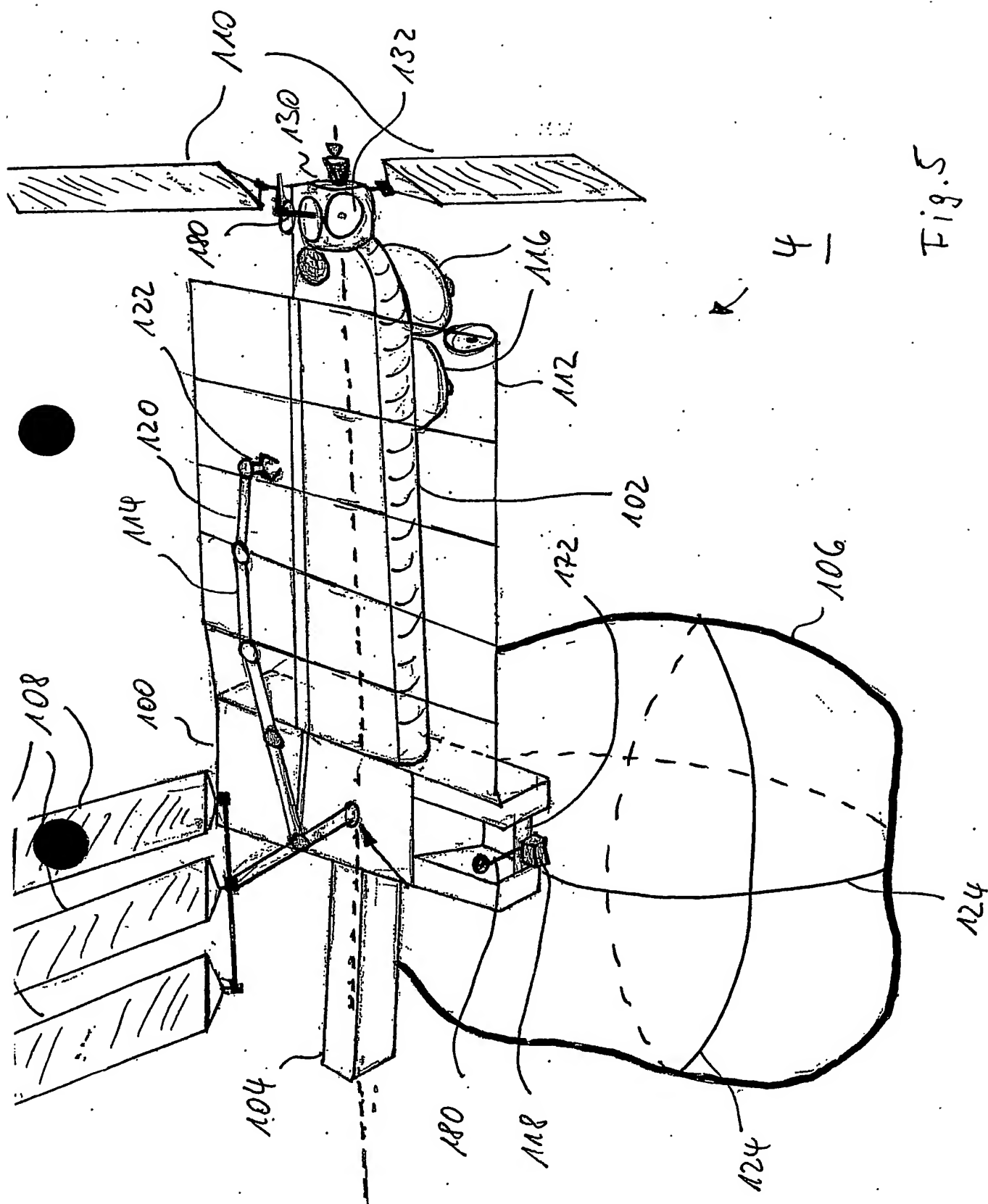


Fig. 4



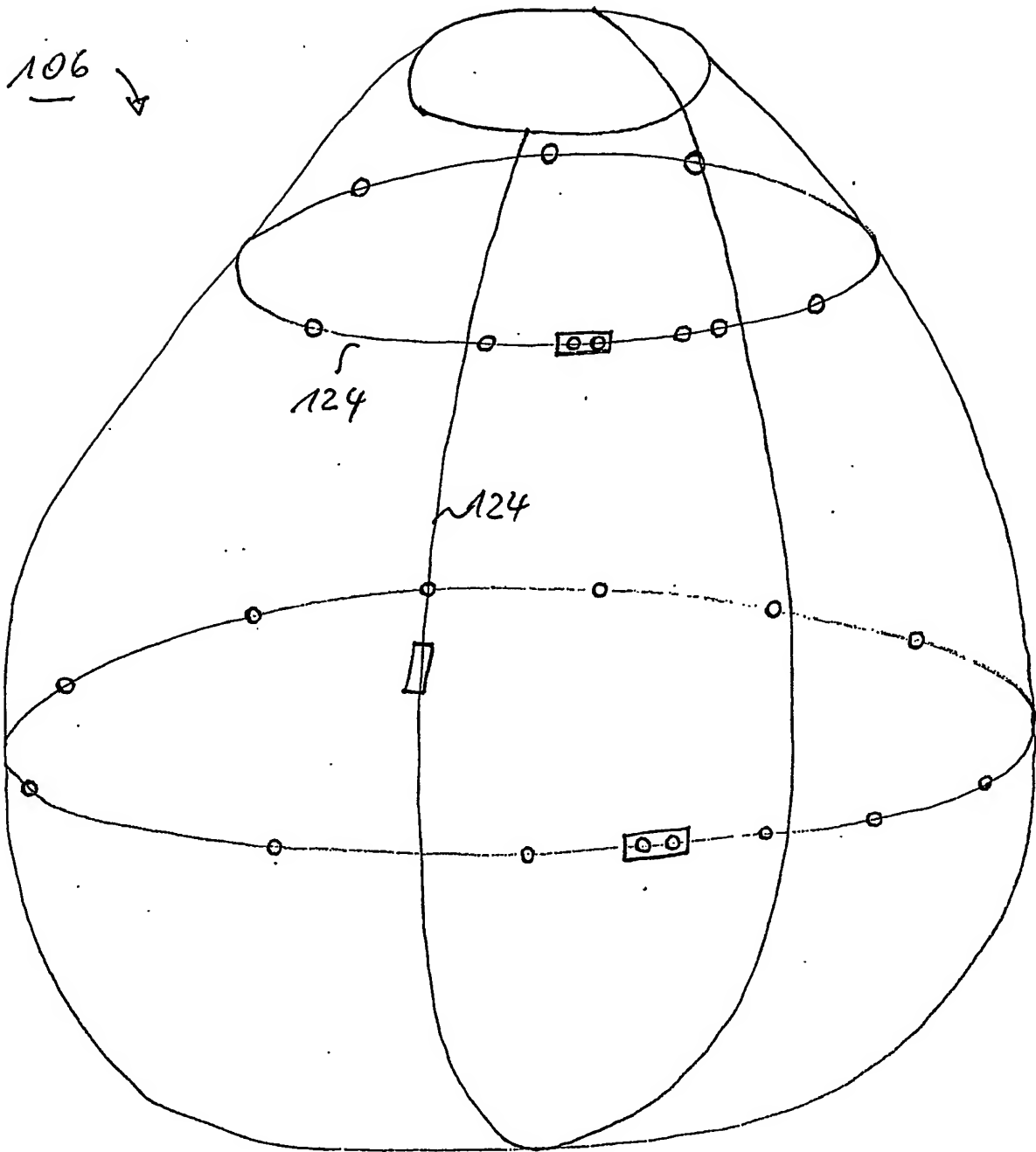
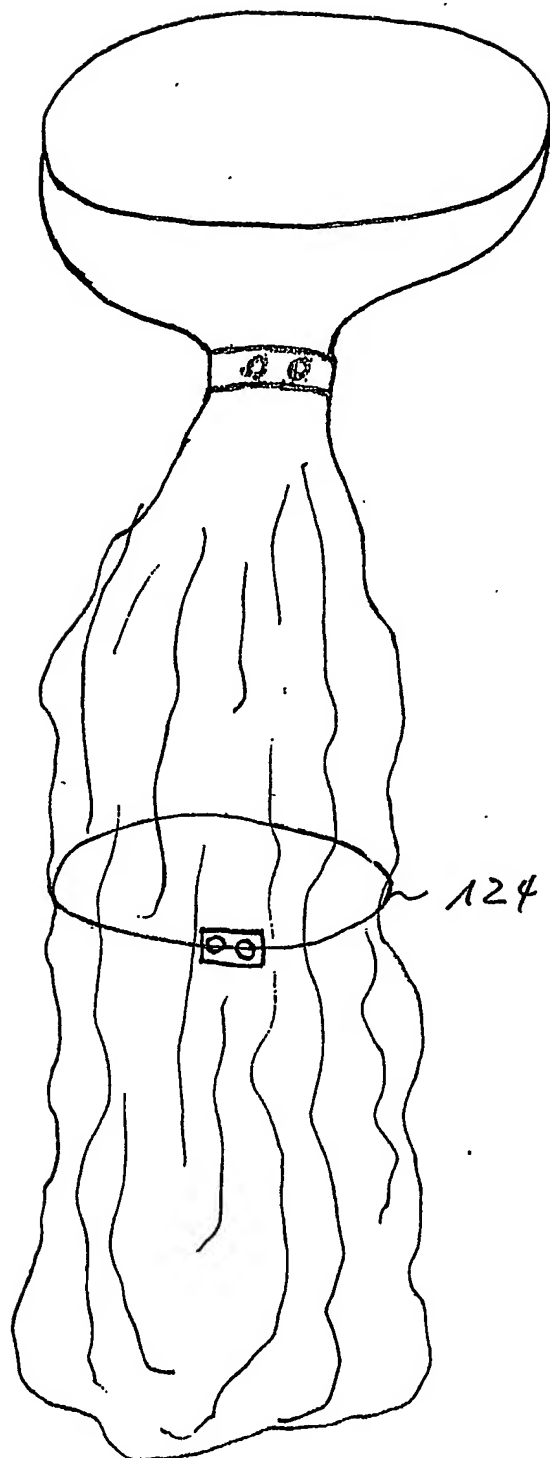


Fig. 6a

106



124

Fig. 66



102

156

130

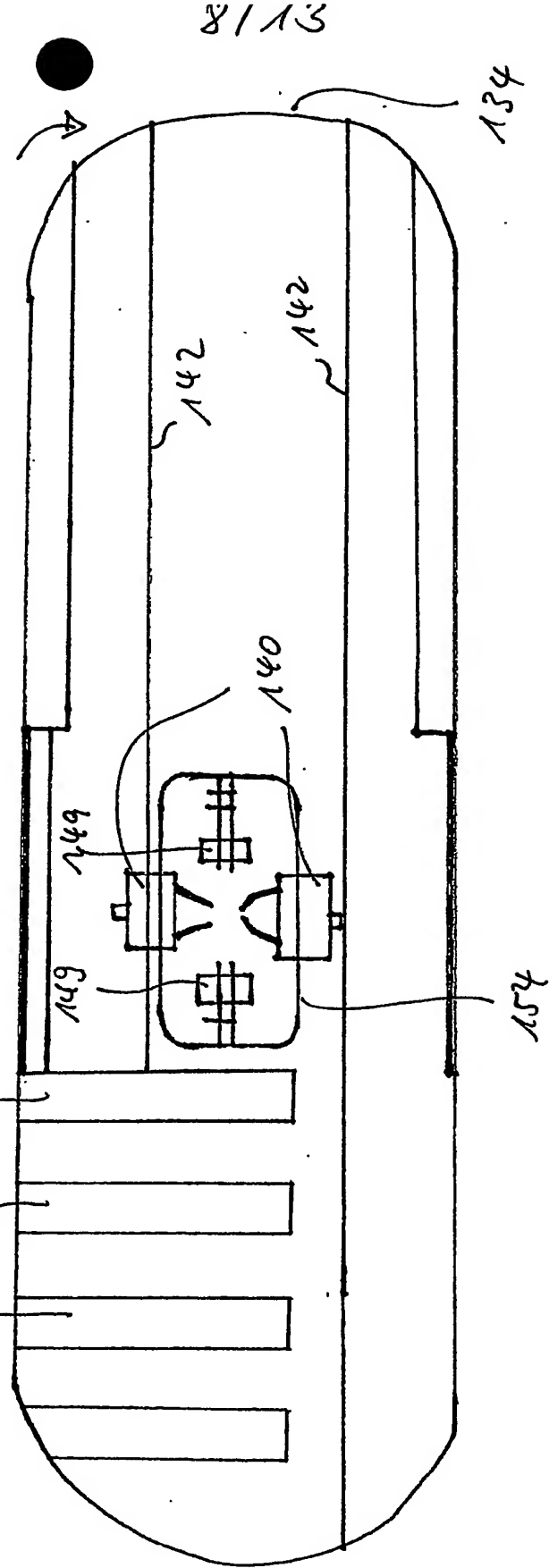
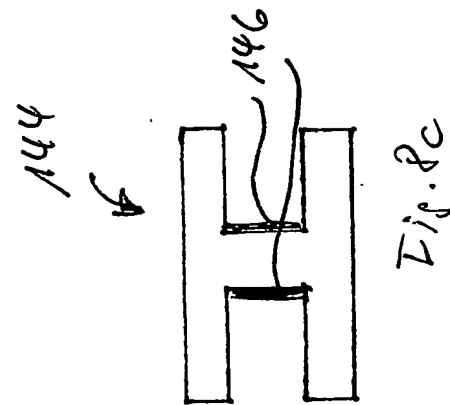
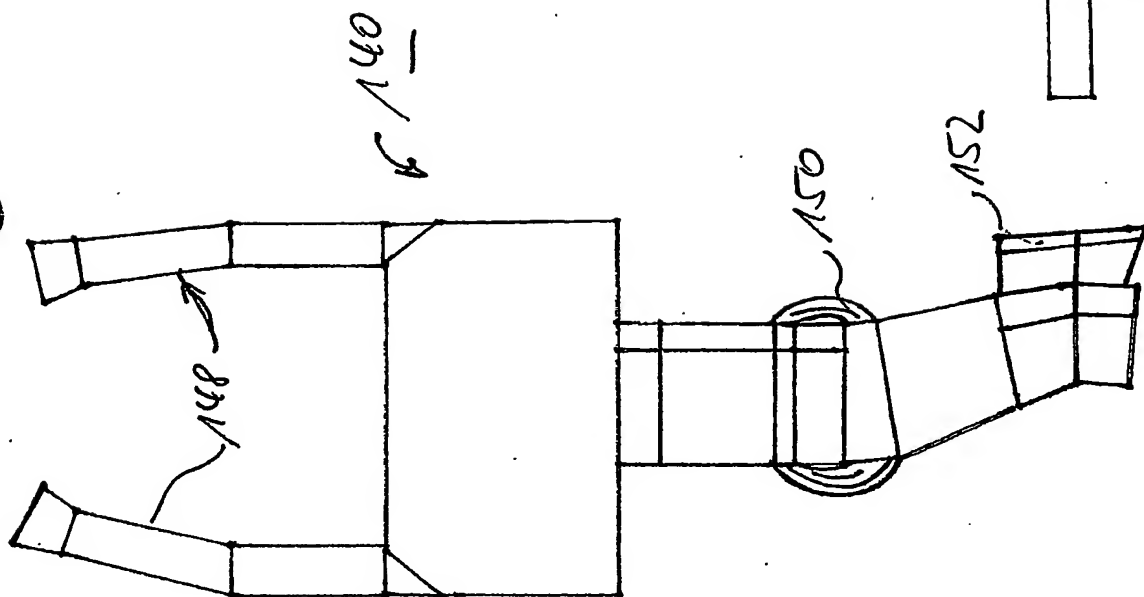
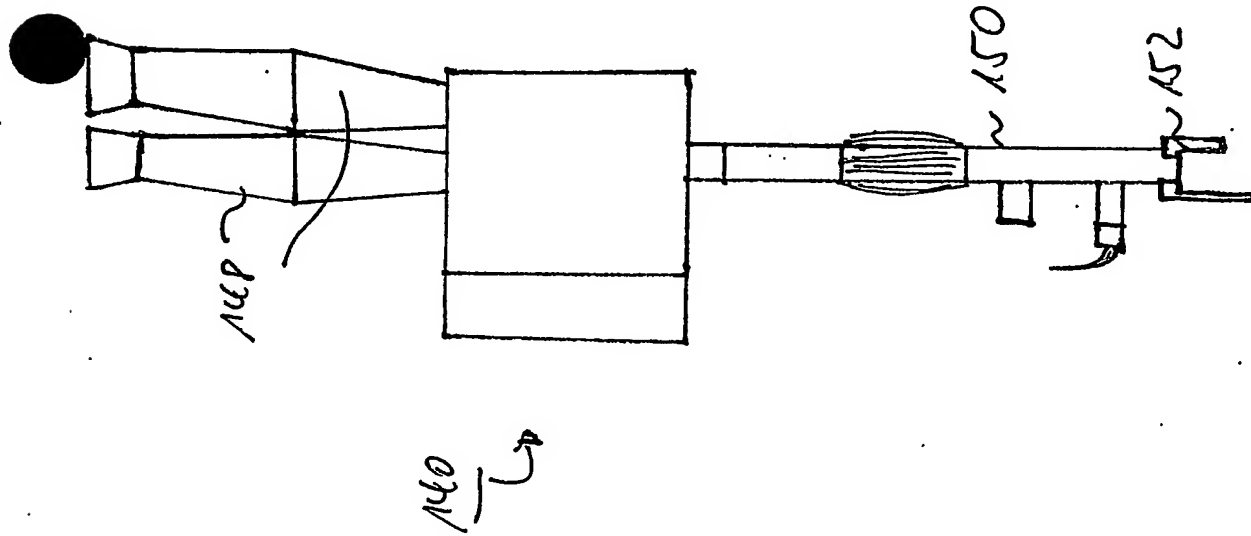


Fig. 7



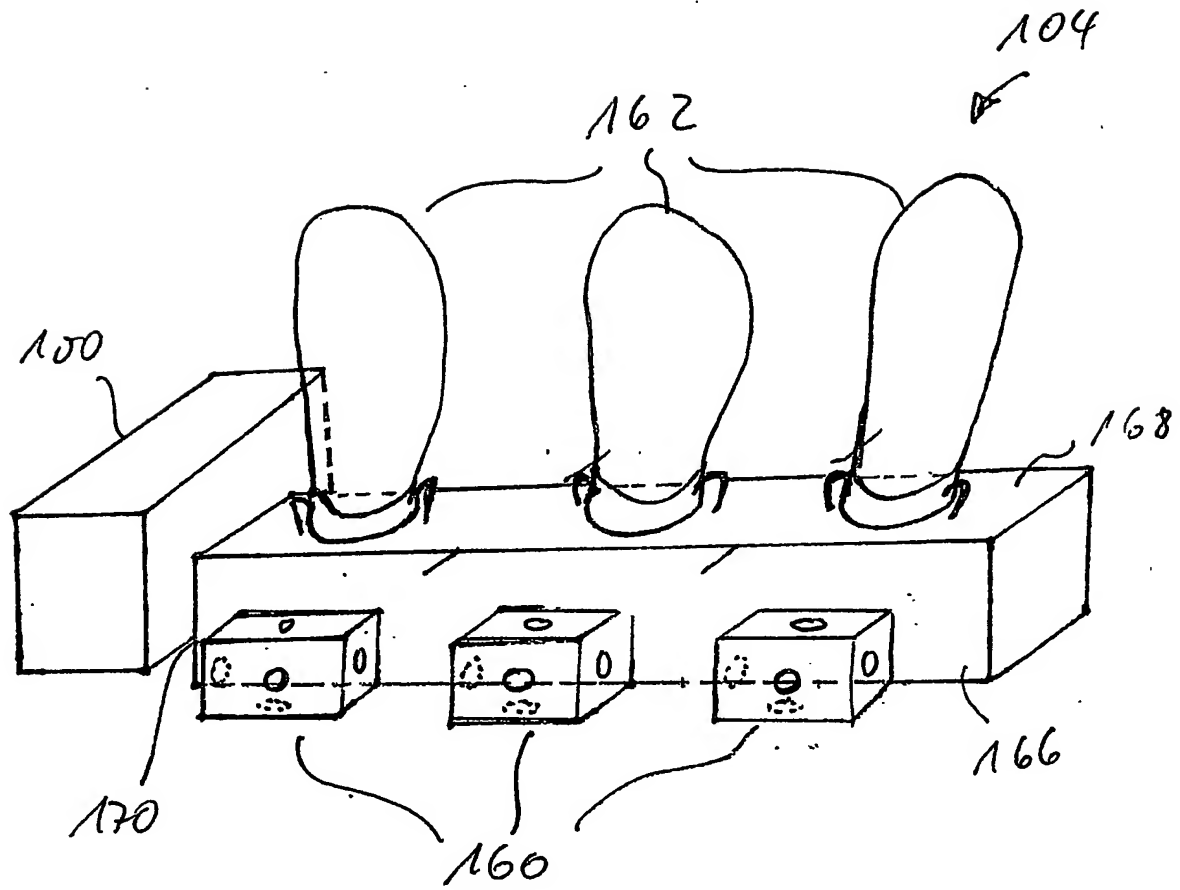


Fig. 9

Fig. 10a

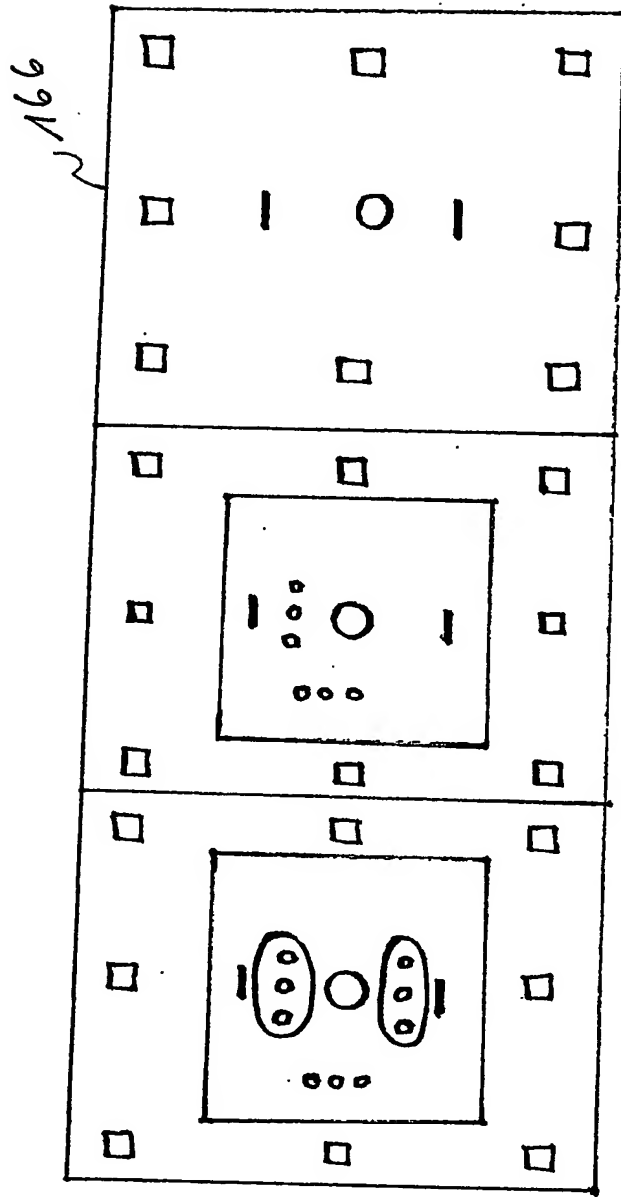
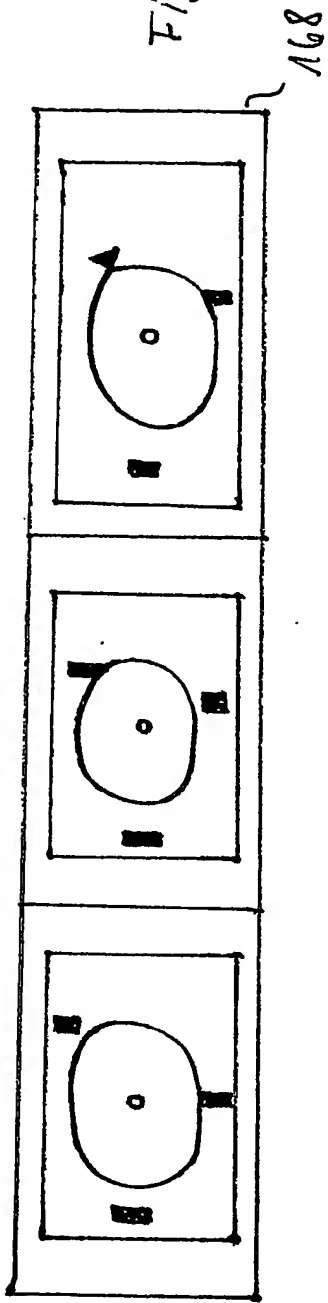


Fig. 106



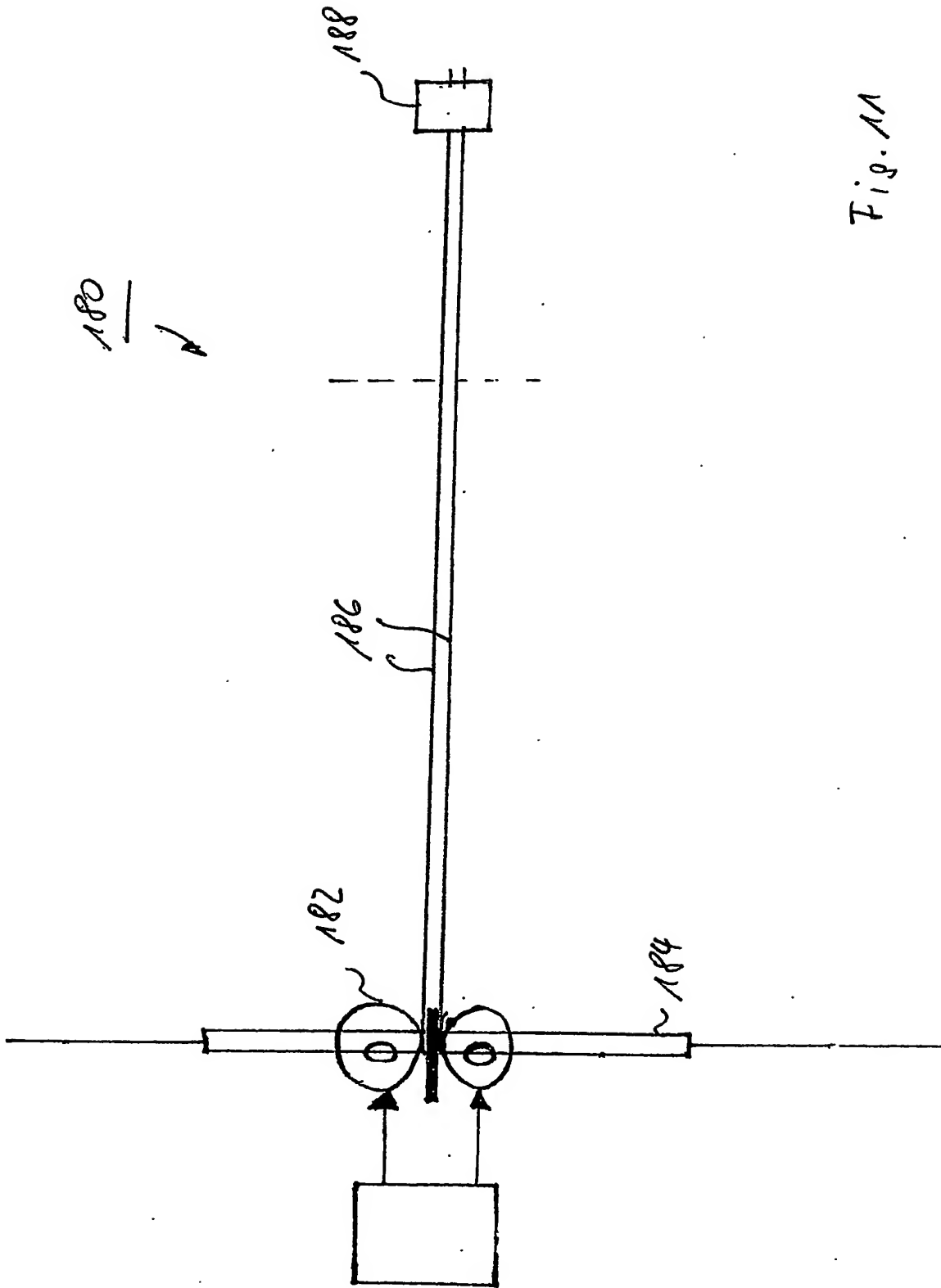


Fig. 11

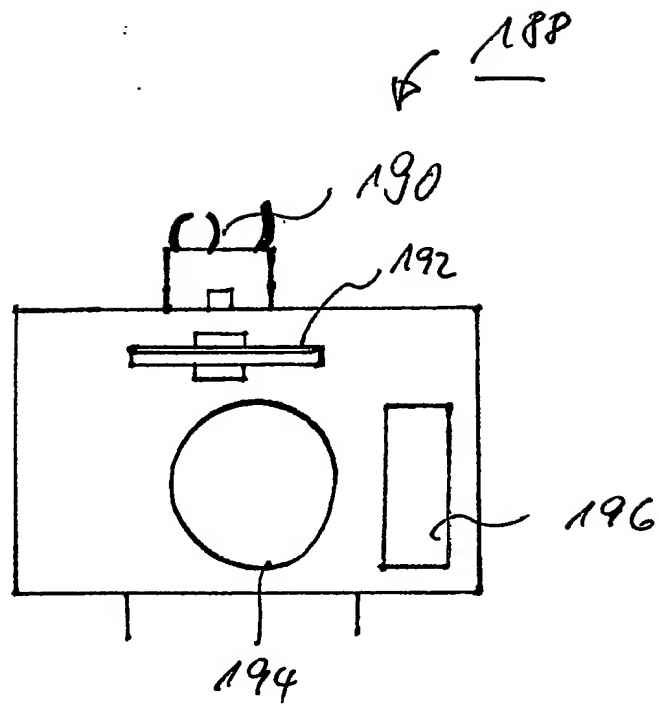


Fig. 12

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